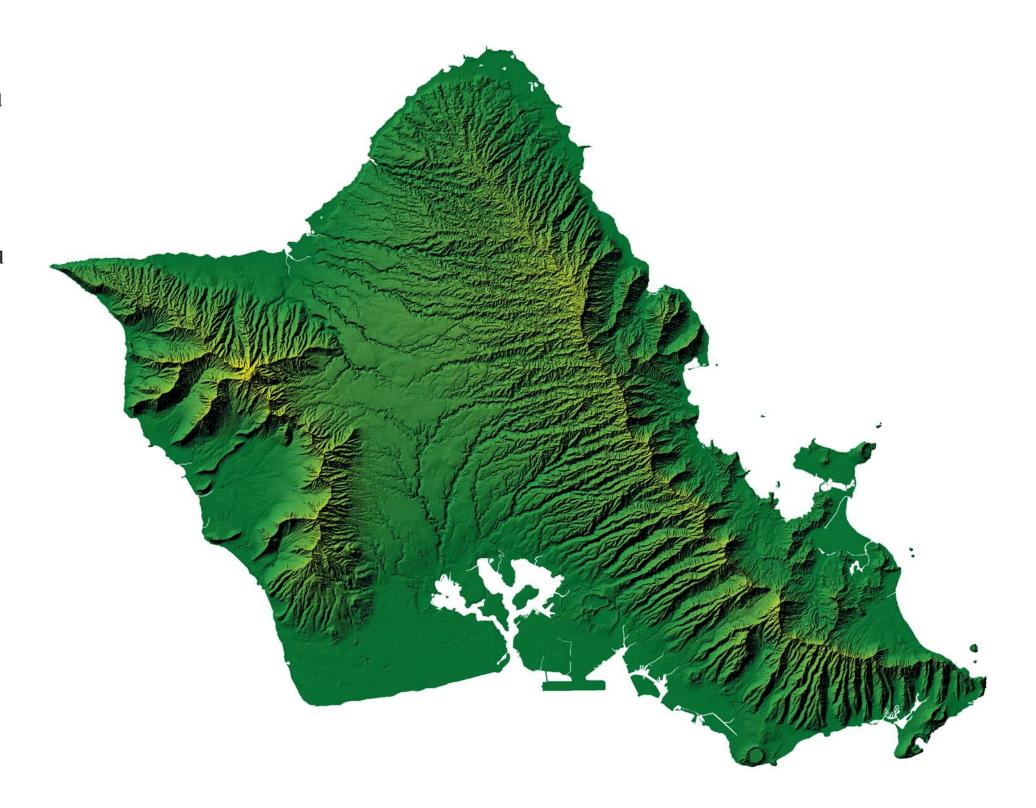
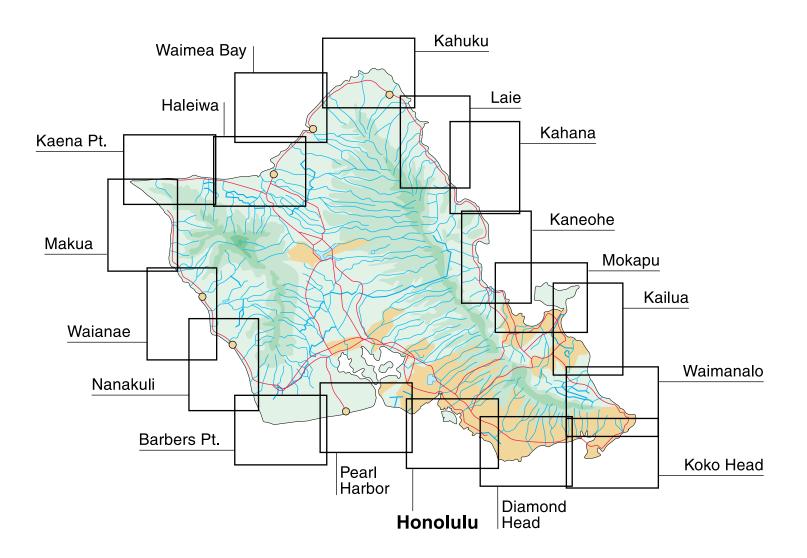
Oahu, the Gathering Place, is the most populated island and Hawaii's government and business center. While it is removed from the active volcanism and seismicity of the Big Island, natural hazards associated with high waves, storms, and flooding annually threaten Oahu's coastal inhabitants and infrastructure. The primary difference between the nature of coastal hazards on Oahu and the rest of the islands is the magnitude of the risk involved. While Oahu has not witnessed a direct hit by a hurricane force storm in its history or suffered damage from a tsunami since 1960, extensive development of the shoreline has continued, apparently as a result of a high level of complacency among developers and the public.



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## **O**ahu

# **Index to Technical Hazard Maps**

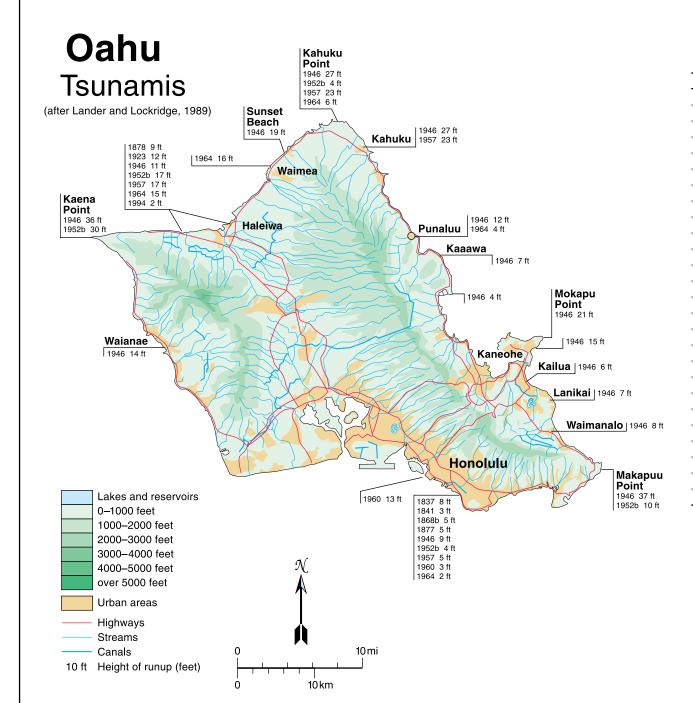


#### **Tsunamis**

tsunami is a series of great waves most commonly caused by violent movement of the sea floor. It is characterized by speed (up to 590 mph), long wave length (up to 120 mi), long period between successive crests (varying from 5 min to a few hours, generally 10 to 60 min), and low height in the open ocean. However, on the coast, a tsunami can flood inland 100's of feet or more and cause much damage and loss of life. Their impact is governed by the magnitude of seafloor displacement related to faulting, landslides, and/or volcanism. Other important factors influencing tsunami behavior are the distance over which they travel, the depth, topography, and morphology of the offshore region, and the aspect, slope, geology, and morphology of the shoreline they inundate. Predicting the specific form of a tsunami at a shoreline is not yet possible because of many factors. History has shown that these factors contribute to a wide range of tsunami runup heights and associated damage even within a very small geographic region. For example, the tsunami generated by the 1946 earthquake in the Aleutian Islands was recorded at Makapuu Point to be 37 ft while in Waimanalo, a mere 3 miles away, the maximum runup was only 8 ft. An important difference between tsunami and ordinary windgenerated waves is that the wavelength (distance between successive crests) of a tsunami can be several orders of magnitude larger. This means that as a tsunami passes an island the water level can rise for several minutes. As a result, tsunami can cause significantly greater flooding than ordinary wind waves of the same height.

History has also shown that damaging tsunamis in Hawaii are generated from distant locations around the Pacific Ocean margins, as well as locally in Hawaiian waters. The source region of tsunami genesis has important implications for the amount of damage caused by a tsunami and for our ability to detect them and respond to their impact. Models show that a tsunami generated in Alaska can travel to Oahu in 5 hr, while a locally generated tsunami, like the 1975 tsunami in Halape, Hawaii, may take only minutes or seconds. Five hours may seem like sufficient time to detect and respond to a tsunami, however, there are few locations above sea level between Hawaii and Alaska where its height and potentially damaging effect can be detected. The island of Midway is the first land a tsunami wave originating in Alaska encounters on its way towards Hawaii. Detection of a tsunami on Midway leaves only 1-2 hr for Hawaiian residents to respond. And even if a tsunami is detected prior to its arrival, predicting its flood magnitude and impact is a difficult challenge because of its chaotic behavior when it makes landfall.

Twenty-six tsunamis with flood elevations greater than 3.3 ft (1 m) have made landfall in the Hawaiian Islands during recorded history, and 10 of these had significant damaging effects on Oahu. This translates into a recurrence interval of one large tsunami reaching Hawaiian shores every 7 yr and one damaging tsunami reaching Oahu every 19 yr. Since the terrible tsunami of 1946, 6 large tsunamis have been recorded in the Hawaiian Islands, and 4 have caused damage on Oahu. The three highest tsunami wave runups recorded on Oahu occurred during the last 53 yr. If



#### Large tsunamis\* (>1m, 3.3 ft) with reported damage in the Hawaiian Islands

Year	Date	Area of origin	Magnitude*
1819	Apr 12	N Central Chile	M= 2.0
1835	Feb 20	Southern Chile	M = 4.0
1837	Nov 7	Southern Chile	M = 3.0
1841	May 17	Kamchatka	M = 2.0
1868a	Apr 3	SE Hawaii	M = 4.1
1868b	Aug 13	Northern Chile	M = 4.3
	Oct 2	South Pacific	
1869	Jul 24	South Pacific	
1877	May 10	Northern Chile	M = 4.0
1878	Jan 20	Aleutian Is (?)	
1896	Jun 15	Japan	M = 4.0
1901	Aug 9	Tonga	
1906a	Jan 31	Colombia/Ecuador	M = 1.0
1906b	Aug 17	Central Chile	M = 2.0
1918	Sep 7	Kurils	M = 3.6
1919	Oct 2	Hawaii (H = 14 ft)	
1922	Nov 11	N Central Chile	M = 3.0
1923	Feb 3	Kamchatka	M = 3.0
1933	Mar 2	Japan	M = 3.0
1946	Apr 1	Eastern Aleutian Is	M = 5.0
1952a	Mar 17	Hawaii (H = 10 ft)	
1952b	Nov 4	Kamchatka	M = 4.0
1957	Mar 9	Central Aleutian Is	M = 3.5
1960	May 22	Chile	M = 4.5
1964	Mar 28	Gulf of Alaska	M = 4.5
1975	Nov 29	Big Island/Hawaii (H = 47 ft)	
			_

\*Reliability of ≥ 3 (of 4)(Lander and Lockridge, 1989), runup > 1m (3.3 ft), and reported damage.

\*\* Tsunami magnitude is defined by M = log<sub>2</sub>H as revised by lida and others (1967), where H is the maximum runup height or amplitude on a coastline near the generating area.

Other tsunamis have occurred, such as that of Oct 1994, however, because of their low (<1 m) runup, insignificant damage, and/or uncertainty surrounding their timing and magnitude as noted in Lander and Lockridge (1989), they were not included here.

one analyzes the last 53 yr in two time slices, 1945 to 1975 and 1976 to the present, a very different tsunami history exists. Between 1945 and 1975, a total of 7 large tsunamis hit the Hawaiian Islands, or one every 3.3 yr, and a damaging tsunami hit Oahu every 6 yr. However, since 1976 not one large tsunami has been recorded in all of Hawaii (1986 and 1994 had 2 small events that were less than 3 ft). The historical record suggests that a damaging tsunami is overdue to reach Oahu's shores. Ironically, it has been during this last 20 yr that development within the Hawaiian coastal zone

has proliferated. If wave runups like those of the 1957 or 1960 tsunamis occurred today, there exists a high probability that low-lying coastal areas such as Waikiki, Waimanalo, Kaaawa, Punaluu, and Nanakuli would suffer damage, primarily because of the risk that has been taken by developing within these inundation zones.



10 km

1996 Nov 14 Honolulu, widespread flooding



[H, hurricane; R, river; Str, stream]

## Stream flooding

loods from stream overflow and high surface runoff (non-channelized flow) are common on all of the Hawaiian Islands and are primarily a result of torrential rains that fall on the steep slopes and small drainage basins characteristic of island drainage systems. The most frequent and severe flooding occurs where steep sloping hillsides abruptly meet flat or low-lying coastal plains, such as those found in Waimanalo, Kailua, Kaneohe, and Laie. Stream mouths are also commonly susceptible to flooding, especially during marine storm or high wave events, as runoff from streams reach a sea that is partly elevated by the combination of high waves, winds, and storm surges. Nearly every year flash floods and prolonged flooding damage property, homes, highways, and crops on each island. Although floods are caused by natural events, most flood damage is a result of human occupation and development of lands that are susceptible to flooding without having provided for adequate protection. As of 1983, floods in Hawaii had claimed more than 350 lives and caused more than \$475 million in damage.

Some of the largest rainfall counts and most severe flooding events have occurred in the last several years. During the first 15 days of November 1996, record-breaking rainfall occurred along the Waianae Coast, where 21 in fell in an area where the average annual rainfall is only 2 in. In Ewa, 12.5 in fell in 7 hr on the 5th of that month, inducing flooding of the low coastal plain. On October 25, 1993, 2-4 in of rainfall caused flash flooding and extensive street flooding throughout the Honolulu area. On the windward side of Oahu, flooding has been common after heavy precipitation such as on April 12, 1994, in Kahuku, November 26, 1992, in Kaneohe, and October 11, 1992. The heaviest rainfall during the last decade in Kaneohe occurred on October 15-16, 1991, when 15 in fell in 48 hr leading to intense flash flooding. A series of slow-moving storms with prolonged rains that saturated the soils of south-central Oahu culminated on New Years Day of 1988 in severe runoff and hillside erosion, resulting in catastrophic damage to stream flood mitigation channels, homes, and roads in Aina Haina and Niu Valleys. Other recent severe events on Oahu include October 1981 flooding of Waiawa Stream after heavy rains that led to \$786,000 damage and January 1968 flooding in Pearl City, which caused \$1.2 million damage. The hazards resulting from stream flooding are significant on all of the islands and should be seriously considered for planning development, as well as for recreation activities.

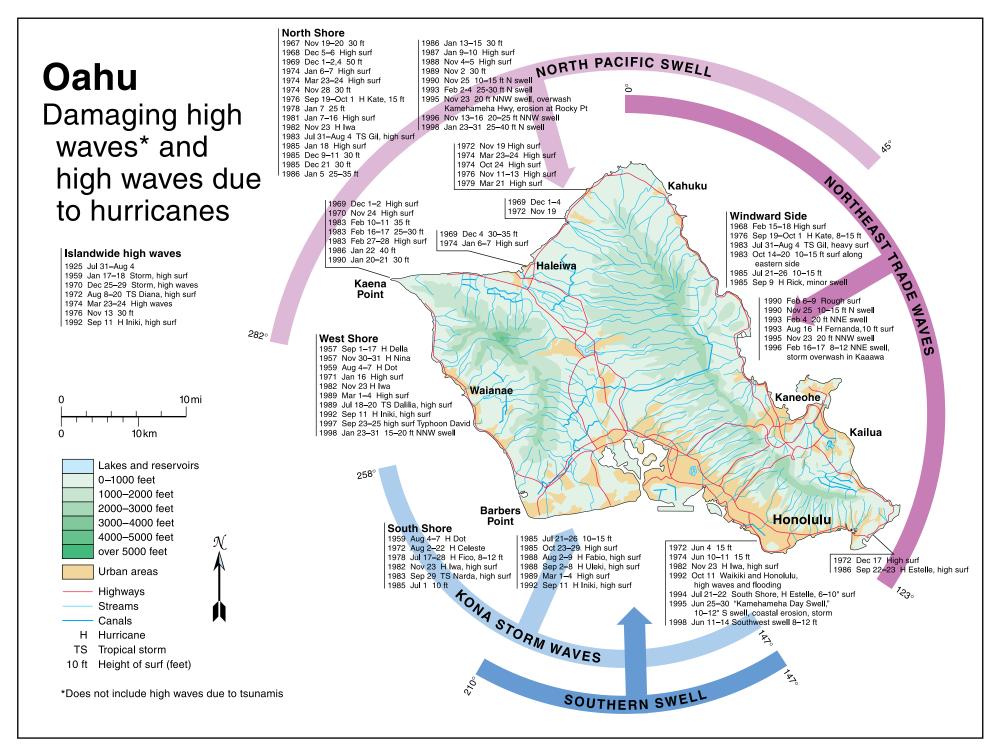
Many formerly flood-prone streams on Oahu have now been artificially channelized to protect development situated on the adjacent flood plain. Although the threat of flood hazard is reduced by this measure, there is a resultant destruction of wetland and stream channel ecosystems that occur. The result is to promote building on former floodplains and the destruction of the riverine environments and estuaries that connect the island's watersheds and reefs.

## **High waves**

igh waves are common along Hawaiian shores, making the islands perhaps the most popular destination for big wave surfing in the world. Lying in the center of the North Pacific Ocean, Hawaii receives high waves from distant storms in the northern and southern hemispheres and from tropical cyclones passing in the vicinity. The hazards associated with high waves include debris overwash, flooding, erosion, high wave energy and turbulence in the nearshore zone, and strong currents. Waves that reach the shoreline are determined by the energy inherent in the approaching swell (a function of wave height and wave length-the distance between successive wave crests), shoreline aspect, slope, morphology and geology, and offshore characteristics including seafloor depth, morphology, and barriers (islands, rocks, reefs, sandbars). When deep-water ocean swells encounter the shallow island margins they rise to great heights because their tops stack up on their slower moving bottoms due to friction along the shallower seafloor. Because the contact between deep water and the shallow margins around the Hawaiian Islands is abrupt, surface waves can grow very tall, very rapidly. Large waves tend to travel in sets, and after breaking they rush up onto the beach temporarily elevating the sea surface near the shoreline. Rip currents form as the water that is pushed up on the shore by successive large waves, tries to flow back to the sea.

The largest waves that reach Oahu generally arrive in winter as a result of intense storm activity in the North and Northwest Pacific. The high amplitude and long wavelength associated with these swells create very large waves with considerable energy. Along the north shore of Oahu, it is common to see wave heights between 15–20 ft annually from winter swell. However, wave heights of 50 ft have been reported, for instance in December 1969 and January 1998. This high wave energy pounds the north and west shorelines as it hits head on, but it can also refract and produce high waves around the entire island. Often, winter north and northeast swells wrap around Makapuu Point and generate waves at Sandy Beach that are as high as the largest summer surf found there. Periodically, as winter mid-latitude storms track northeast of the islands toward the mainland, they will generate swell that impacts the east sides of the islands. In the summer, south-facing shorelines receive 4-6 ft swell from distant storms in the Southern Hemisphere. South swells tend to have less energy than winter swells, but because their source can be as far away as New Zealand, they can have very long periods. Trade wind waves can be high, but because of their shorter wavelengths, they have less energy than north and south swell. Trade wind swell has a greater easterly directional component, which enables them to refract around to south and southwestfacing shorelines producing wave heights of 1-4 ft.

High waves from hurricanes present a more complex hazard, as they may coincide with high tide, storm surge, and wind and wave setup, to produce a combined threat. High waves from hurricanes generally occur during hurricane season between June 1 and December 1. High waves from

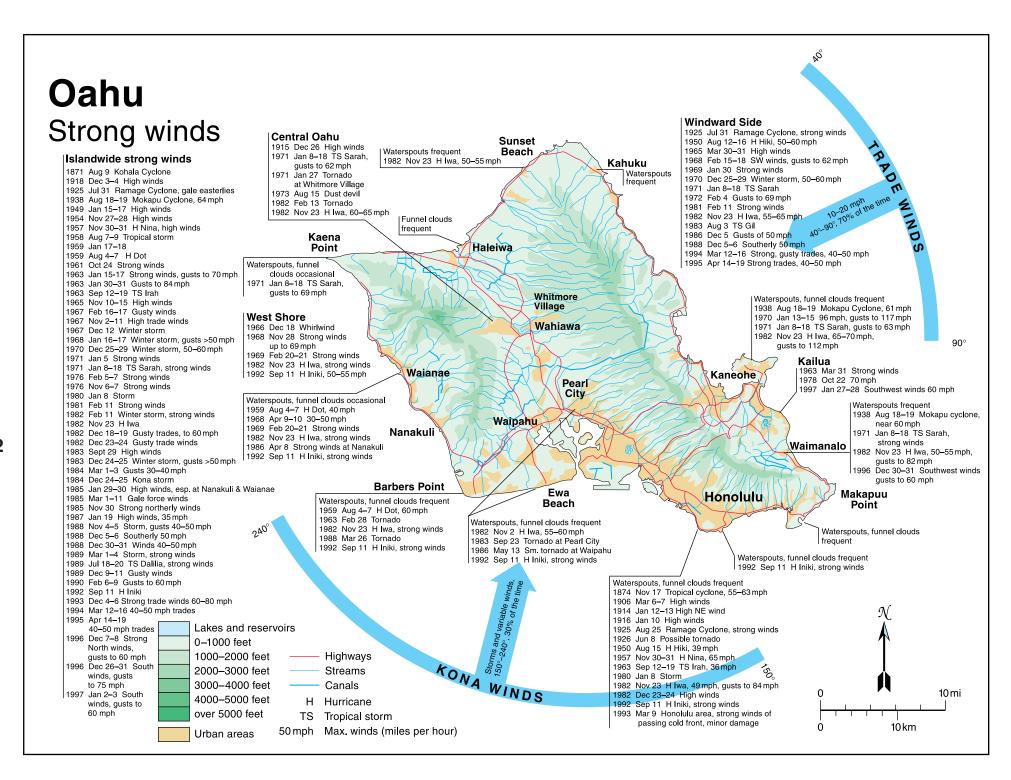


hurricanes most often hit the eastern shores as hurricanes approach the islands from the east, and south- and west-facing shorelines as the storm passes to the south and west. Hurricane generated waves have exceeded 15 ft along east Oahu and 20 ft on Oahu's southern shores. Combined with storm surge and high tides, hurricane waves can overwash coastal roads and properties, as they did along the Kaaawa and Kaneohe coasts during Hurricane Fernanda in 1993 and along the Honolulu and Waianae coasts during Hurricane Iniki in 1992.



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## **Strong winds**

Winds on Oahu originate from three main sources: trade winds, Kona winds, and hurricanes or tropical storms. Northeast trade winds are dominant throughout most (70%) of the year and generally range in velocity between 10 and 20 mph. However, trade winds of 40-60 mph occasionally occur for several days at a time when the sub-tropical high-pressure cell located in the central North Pacific Ocean intensifies. During the 1993–1994 and 1994–1995 winter seasons, for example, strong and gusty trade winds of 40 to 50 mph lasted several days and inflicted damage to roof tops, tree limbs, and telephone equipment. The east-facing coastlines, as a result, are the windward coasts and most impacted by trade wind energy. Kona winds are southerly winds and occur as light and variable winds during summer months when trade wind circulation breaks down, but in winter they can be very strong when storm systems moving across the central North Pacific draw air from the south toward their low pressure troughs. Damaging Kona winds from storms generally occur during the winter and spring seasons and have reached velocities of 50 mph for several days on end.

Damaging winds on Oahu and in Hawaii are most commonly associated with passing tropical cyclones (hurricanes, tropical storms, and tropical depressions). Historically, most tropical cyclones have passed the Hawaiian Islands to the south and west. Because they spin counter-clockwise in the Northern Hemisphere, east-facing coastlines in Hawaii receive the brunt of strong onshore winds as storms approach the islands, while the south and west coastlines feel onshore winds as the storms pass to the west. The highest wind speeds, however, may occur on the side opposite the storm approach, as localized microbursts and downdrafts accelerate downslope as they descend over the palis (cliffs). As Hurricane Iwa passed west of Oahu the highest winds were observed at the base of the Pali in Kaneohe. Even so, coastlines facing the passing storms usually are adversely impacted by both wind and storm surge damage, like the Waianae Coast was as Hurricane Iniki passed to the west, before slamming into Kauai. History has shown that the islands do not have to take a direct hit from a storm to sustain a high level of damage. Wind strength, storm diameter, timing, and proximity, are important factors that control storm impact to the coastal zone.

#### Honolulu

he heavily developed coastal metropolis of Honolulu and Waikiki is built on a low-lying coastal plain, which was submerged by a higher relative sea level approximately 125,000 yr ago and again as recently as 1,500 to 4,000 yr ago. In response to erosion and other hazards, an extensive complex of shoreline protection structures, including groins, seawalls, and revetments has been implemented to protect the densely developed seaside. Once home to Hawaii's legendary surfer and Olympic gold-medal swimmer, Duke Kahanamoku, Waikiki attracts many visitors each year who relax on the beautiful white sand beaches. Ironically, these beaches are also largely a human fabrication. Early in the 1900s, sand was imported to create an extensive artificial beach where only a narrow sand strip fronting coastal wetlands and tidal marshes formerly existed. They continue today to be nourished by sands brought in from elsewhere on the

The coast steepens at the foot of the prominent and geologically-young crater of Diamond Head, known as Puu Leahi. A nearly continuous fringing reef parallels the coast at Diamond Head, and widens to the west. The bottom remains shallow far offshore along this entire region. The reef has been dredged to form a channel at the outflow of the Ala Wai Canal, which empties the Manoa and Palolo streams, and on both sides of Sand Island, to provide for commercial shipping. Land reclamation on the reef has occurred at the airport, Sand Island, and Ala Moana.

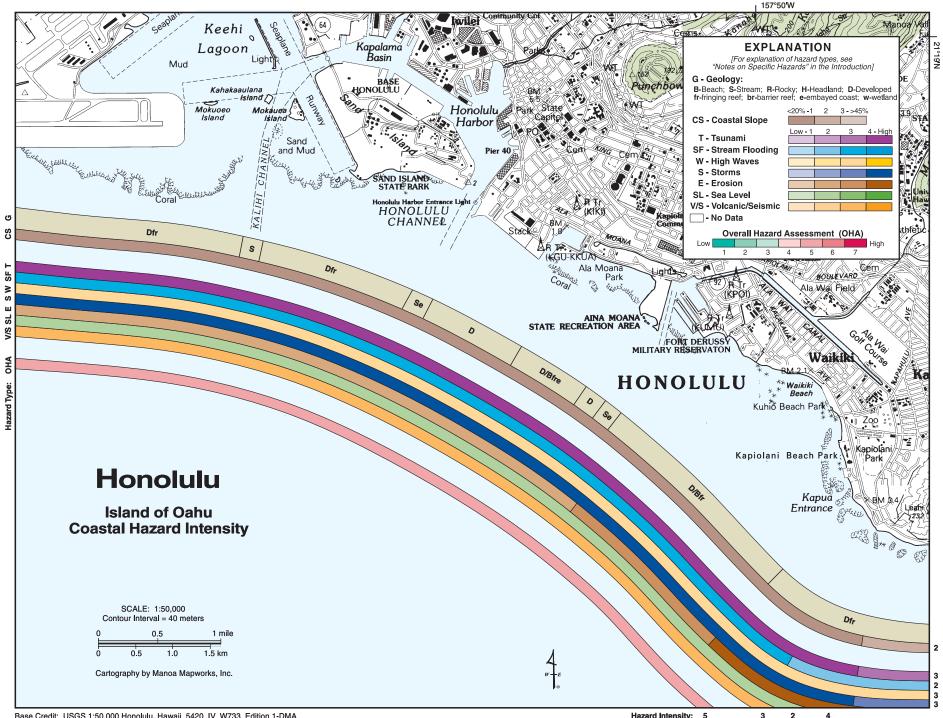
A moderate to high (5) Overall Hazard Assessment (OHA) for the Honolulu coastal zone is principally dictated by the low coastal slope which is especially susceptible to damage resulting from tsunami, stream flooding, hurricane storm surge, and seasonal high-wave flooding. Tsunami and storms are ranked high while stream flooding and high seasonal waves are moderately high. These rankings are supported by a his-





tory in Honolulu of severe flooding from both storm surge and stream runoff from the steep surrounding hillsides of the Koolau Range. Although Honolulu has yet to experience a direct hit from a major hurricane or tsunami, a complacency may exist among its inhabitants that hurricanes tsunamis are not major threats to this coast. Facing southwest, however, coastal Honolulu is extremely vul-

TOP: Waikiki, about 1958 BOTTOM: Waikiki, about 1984

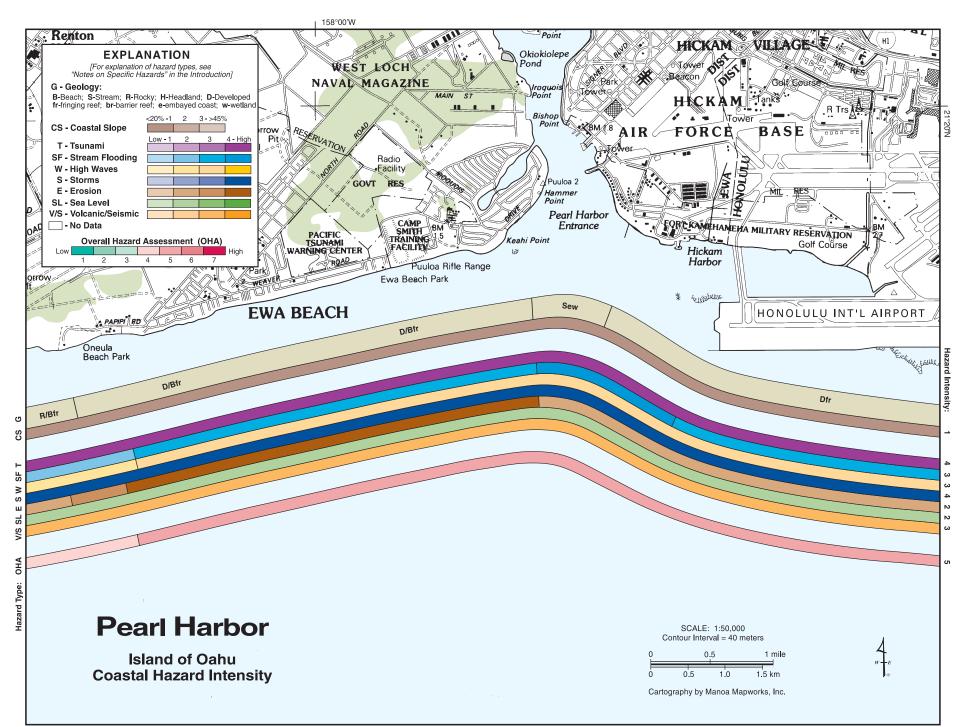


Base Credit: USGS 1:50 000 Honolulu, Hawaii, 5420, IV, W733, Edition 1-DMA

nerable to strong winds and waves generated by tropical storms that most frequently pass the Hawaiian Islands just west of Oahu. While observations of tsunami flooding have not exceeded 8 ft, Honolulu has experienced extraordinary coastal development within the elevation range of historical tsunami runups. The threat from high waves is moderate to high because this region regularly receives wave heights on the order of 6 ft from south swell. As recent as the summer of 1995, however, waves as high as 12 ft pounded the Honolulu shoreline causing significant flooding and erosion along the waterfront of Waikiki's seaside hotels and Kuhio Beach Park. Erosion is high at the foot of Diamond Head (at the southeast corner

of this map) and moderately high throughout Waikiki, where seawalls and groins have been placed to reduce coastal erosion. West of Ala Moana Park, erosion is reduced to moderately low, because of the buffering effects of the wider fringing reef offshore. Sea-level rise in this region is ranked moderately low relative to the higher rates on Maui and the Big Island. Seismicity along the Honolulu coastline, like the southern half of Oahu, is ranked moderately high because it is within the Molokai Seismic Zone.





Base Credit: USGS 1:50,000 Nanakuli, Hawaii 5320 I W733 Edition 1-DMA and USGS 1:50,000 Honolulu, Hawaii 5420 IV W733 Edition 1-DMA



The low Ewa coastal plain is fringed by narrow sandy beaches and a wide, shallow reef flat offshore.



#### **Pearl Harbor**

he entrance to Pearl Harbor separates the beaches along the coastal plain of Ewa to the west from the isolated and less accessible shores of Hickam Air Force Base and the Honolulu International Airport to the east. Fringing reefs parallel the coastline extending nearly one mile offshore, except at the mouth of the harbor. Here, sediments transported from the central plain of Oahu by streams descending from both the Koolau and Waianae ranges meet the sea and form an embayed wetland environment ringing the shores of Pearl Harbor. The shallow nature of the broad fringing reef at Ewa is effective at intercepting waves and dissipating their energy far offshore of this low-lying and very gently sloping coast. Extensive land reclamation has transformed the coastline near the airport and Pearl Harbor entrance. The coastline in the vicinity of Ewa Beach appears to be actively eroding even under relatively low wave activity. Seawalls and rockpiles surround the harbor entrance and airport runways in the east, while small jetties, groins, and seawalls have been emplaced along the narrow sandy beaches of Ewa.

The Overall Hazard Assessment (OHA) for the Pearl Harbor coastal region ranges from moderate to high (5) at the mouth of Pearl Harbor to moderate (4) west of Oneula Beach Park, primarily as a result of the low slopes found along the seaward edge of Oahu's largest drainage basin. The low-lying coastal plain surrounding Pearl Harbor is susceptible to wave inundation so the tsunami threat is ranked high. This coast becomes increasingly arid to the west, and as a result, the stream flooding hazard is reduced from high near the harbor mouth to moderately high on each side and moderately low west of Oneula. Although annual wave heights reach 4-6 ft from south, southwest, and refracting northwest swell, the hazard from high waves is reduced to the west of Oneula Beach Park, where shallow fringing reefs extend far offshore and help to dissipate wave energy. As a result, the high-wave hazard is moderately high east of Oneula and moderately low to the west. Historically, the region has yet to experience the direct hit of a hurricane, however, because it faces south it is vulnerable to high winds and waves generated by tropical storms that commonly pass to the west of Oahu. Erosion is moderately low east of the harbor mouth, and high along the Ewa Beach coastline, where a recent proliferation in seawalls and revetments has exacerbated beach loss. It is moderately high along Oneula and moderately low to the west. The threat of sea-level rise is ranked moderately low, while the seismic hazard is moderately high due to the nature of the unconsolidated sediments upon which portions of this area are developed. The volcanic/seismic hazard along the Pearl Harbor coastline is moderately high.

#### **Barbers Point**

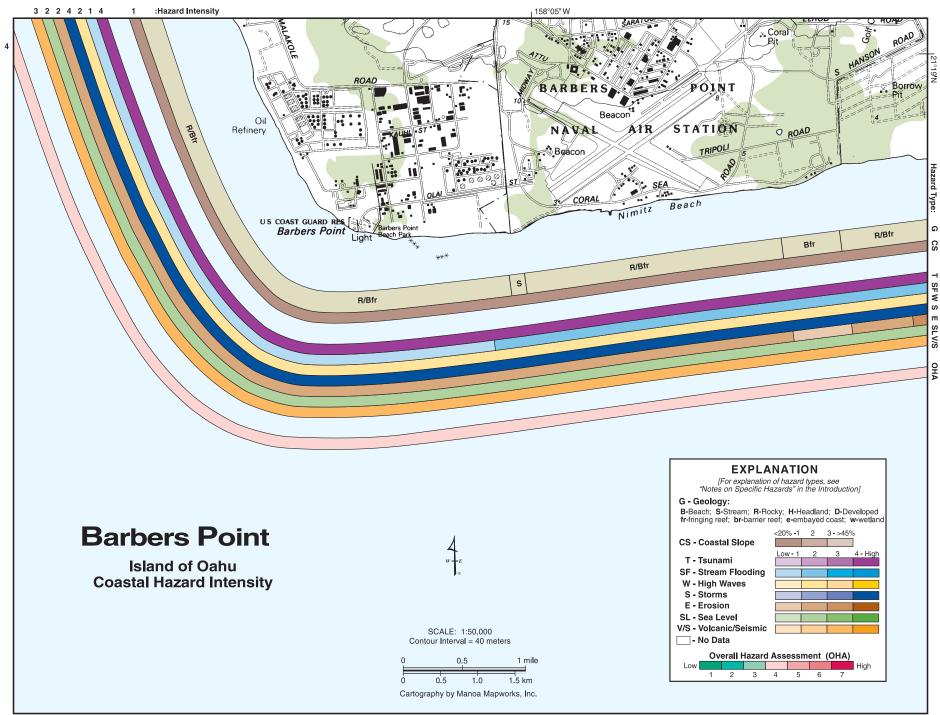
he remote coast of Barbers Point is a broad nearly flat marine terrace underlain by reefs formed by the Waimanalo Stand of the Sea, 125,000 yr ago. It is also one of the driest areas on Oahu. Small 3-6 ft rocky outcroppings of fossil reefrock extend from Nimitz Beach in front of Barbers Point Naval Air Station around the point to the oil refinery in the west. This coastal zone has a very low slope. Poorly defined fringing reefs run the length of this coast where the nearshore zone is largely comprised of a hard coral and calcareous algae reef bottom interrupted in a few locations by small sand channels. Because Barbers Point faces due south, it is susceptible to Kona storms, tropical storms, and waves coming from the south. It also extends sufficiently to the west that it can experience significant swell wave energy refracting around the island from the north. The Alaskan earthquake of 1946 brought 12 ft tsunami waves to Barbers Point, while just to the east at Ewa Beach, the highest recorded tsunami runup was 3 ft.

The Overall Hazard Assessment (OHA) for the Barbers Point coast is moderate (4), primarily due to the high storm and tsunami hazards. The low coastal slope of Barbers Point makes this region vulnerable to inundation and flooding associated with high waves and tsunamis. As a result, the hazard due to tsunami is high. The storm threat is also ranked high



Oahu's oil refineries are built on this low-lying Barbers Point coastal plain, which rises only  $\sim$ 1–2 m above sea level.

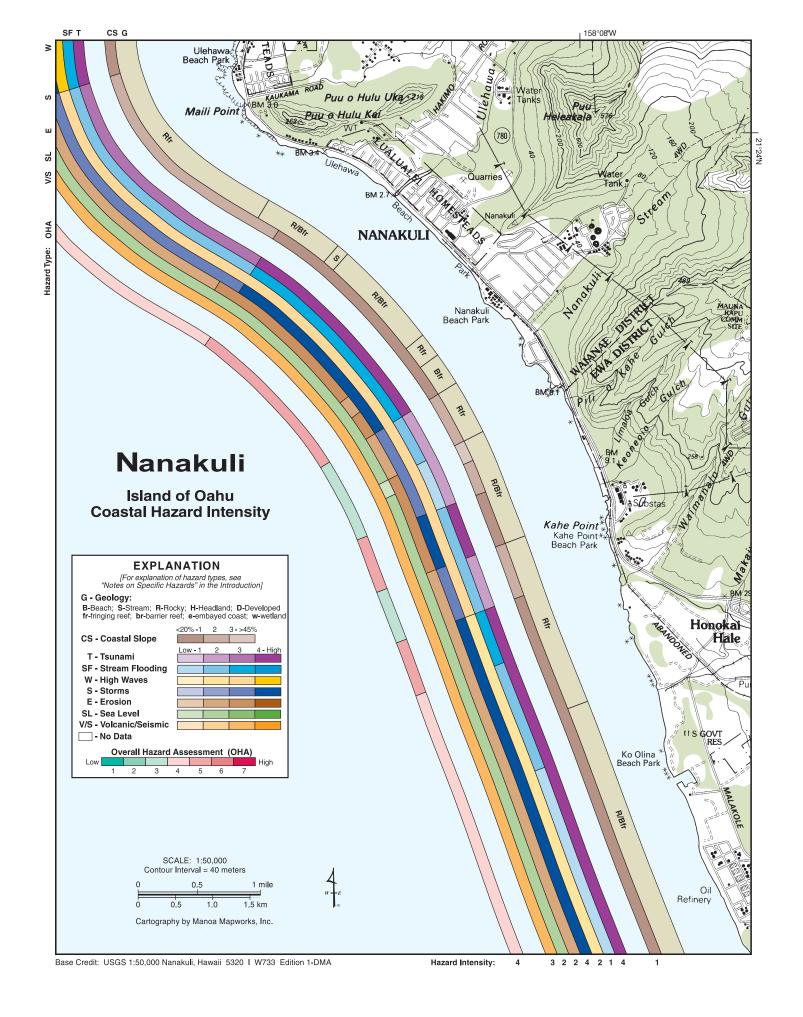
along this coast, as hurricane inundation, including that from Iniki (1992) and Iwa (1982), has historically been damaging to this and other southfacing coastlines. Stream flooding, however, is ranked moderately low to low because it is very arid in this region and far removed from the drainages of the Koolau and Waianae ranges. The hazard due to high seasonal waves is ranked moderately low because this region largely experiences moderate wave energy from south swell. The hazard due to erosion is slight and is ranked moderately low along the rocky cliffs of Barbers



Base Credit: USGS 1:50,000 Nanakuki, Hawaii 5320 I W733 Edition 1-DMA, and USGS 1:50,000 Honolulu, Hawaii 5420 IV W733 Edition 1-DMA

Point and low in front of the isolated sandy beach at Nimitz Beach. The threat from sea-level rise is somewhat mitigated by the rocky coastline and is ranked moderately low here as in most of Oahu. The volcanic/seismic hazard is ranked moderately high, as is the southern half of Oahu, due to a history of occasional significant seismic activity.







#### Nanakuli

Honokai Hale, marks the southernmost portion of the west coast of Oahu. Small pocket beaches of sand and/or basalt boulders lie between lengthy expanses of 6-10 ft high rocky cliffs of old reefrock and/or beachrock. Several sandy beaches are perched on top of reefrock and beachrock at the water's edge. Offshore, the seafloor is largely a hardground of reef separated by occasional small sand channels and a few larger sand fields inside an extensive complex of submerged fringing reefs. The slopes are relatively gentle along this coast but steepen around Maili Point, where signs of headland slumping can be seen on Puu o Hulu Kai. Seemingly protected behind Maili Point, the town of Nanakuli actually has experienced considerable inundation from high waves. Tsunami heights of 20 ft from the 1946 Alaskan earthquake were recorded in Nanakuli, whereas farther northwest in Waianae (see Waianae map) the same event produced only 12 ft floodwaters.

The Overall Hazard Assessment (OHA) for the Nanakuli coastline is moderate to high (5) in the low-lying coastal town of Nanakuli and at the two isolated beaches just north and south of Kahe Point Beach Park. These areas are most susceptible to tsunami, stream flooding, high winds, and storm surge. The OHA is moderate to low (3) at Kahe Point and along the small

rocky shore where Pili o Kahe Gulch meets the sea. The OHA is moderate (4) south of Kahe Point Beach Park to Ko Olina, and along Maili Point. Tsunami and storm hazards along this coast are ranked high from Ulehawa to Nanakuli Beach Park, just north of Kahe Point Beach Park, and the southern region near the oil refinery and power plant, where the coastal slopes are lowest. Both are ranked moderately high along the steeper rocky areas between. Stream flooding is ranked moder-



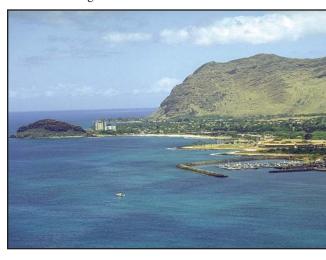
The artificial coves of Ko Olina provide sandy beaches along an otherwise rocky shoreline.

ately high for the Nanakuli coastal plain and the beach seaward of Honokai Hale, and moderately low and low for the steeper areas. The high wave hazard is ranked moderately high along low-lying Nanakuli, which receives larger winter waves, and moderately low to the south where the slope is relatively steeper and the coast farther removed from influence of winter swell. Erosion is moderately high for sandy and rocky low-lying beaches and moderately low where rocky cliffs help mitigate loss of coastal land. Sea-level rise is moderately low throughout this coast, except at the isolated and steep rocky outcrop just south of Nanakuli Beach Park where it is ranked low. The volcanic/seismic hazard here, like the southern half of Oahu, is ranked moderately high because of its proximity to the Molokai Seismic Zone and history of seismicity during the last 200 yr.

#### Waianae

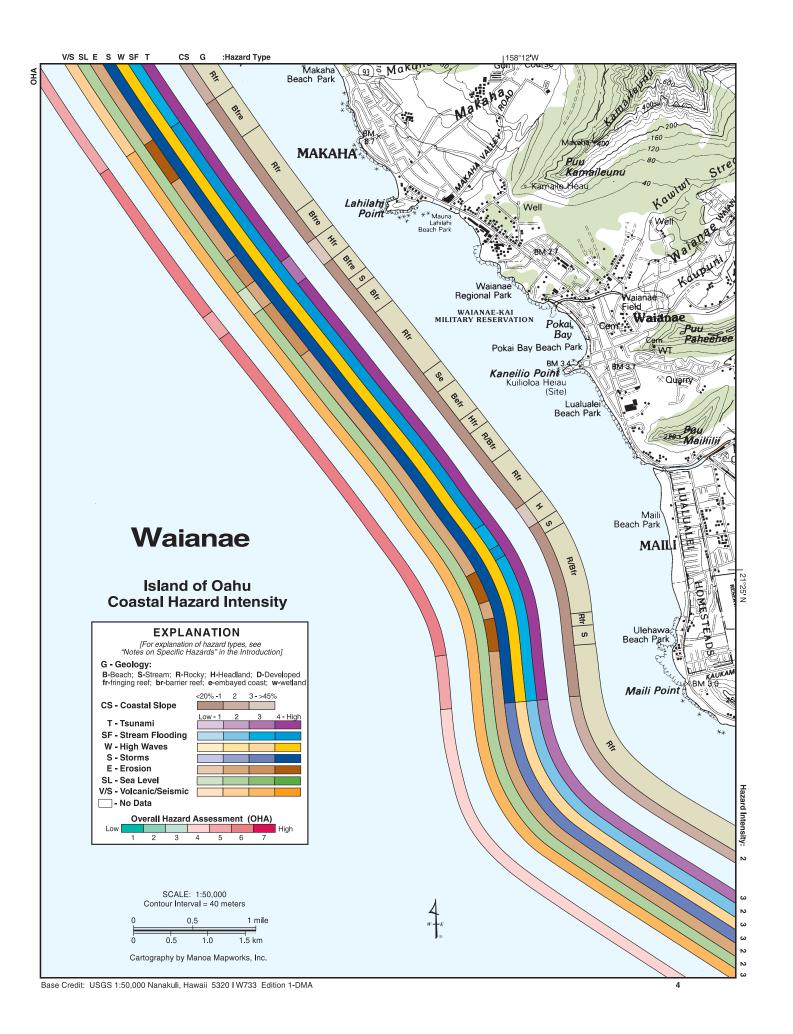
**B** eautiful sandy beach embayments separated by spectacular basaltic headlands mark the Waianae coast. Streams, most channelized into drainage canals, empty deeply incised valleys on a low-lying but narrow coastal plain of emerged fossil limestone reef rock that formed about 125,000 yr ago when sea level on Oahu was higher than present. Seawalls have been built along many of the seaside properties, and large boulder breakwaters guard Pokai Bay and the Waianae Small Boat Harbor. Beach widths at Maili and Makaha can vary by 145 ft annually due to seasonal changes in wave energy. In the long term it appears that the central portions of these beaches have accreted at the expense of their margins. Fossil reefs separated by scattered sand-rich channels and scoured surge channels lie offshore just landward of a relatively extensive fringing reef. Except for Lahilahi Point (Black Rock), a volcanic headland, the majority of this coast maintains very low slopes, and as a result, has experienced damaging floods from streams and inundation by hurricane storm waves. Facing southwest, the Waianae coast has historically received significant wind and wave energy associated with passing tropical storms that tend to track just west of Oahu as they pass the Hawaiian Islands. Two storms of recent memory, Hurricanes Iwa (1982) and Iniki (1992) generated damaging high waves, and the associated storm surge produced coastal flooding to an elevation of 11 ft above mean sea level and higher.

From Makaha to Maili Point, the Overall Hazard Assessment (OHA) is high (6) where hazards due to tsunami, stream flooding, high waves, and storms are individually ranked high, largely because of the lowlying, gradually sloping coastal plain. Flood inundation heights of 12 and 14 ft were recorded in this region during the 1946 and 1957 tsunamis, respectively. Flash floods and stream floods, sometimes lasting two or three days, have occurred rela-



Waianae Small Boat Harbor and Lahilahi Point (Black Rock) to the west.

tively frequently along the Waianae coast. As a result, stream flooding hazard is ranked moderately high south of Maili, and high north of Maili Beach Park, where several streams drain inland valleys along the low coastal plain. Only at the headlands of Lahilahi and Maili Points is the overall hazard assessment reduced to moderate to high (5), due to the moderately high tsunami threat and moderately low erosion hazard there. South of Maili Point, where the tsunami, high waves, and storm hazards are reduced to moderately high, and stream flooding is moderately low, the overall hazard is ranked moderate (4). Erosion is ranked high at the west end of Ulehawa Beach Park and Makaha, and moderately high along the low-lying beach embayments on either side of Lahilahi Point. Sea-level rise is ranked moderately low and low throughout the region. The volcanic/seismic hazard here in the southern half of Oahu is ranked moderately high.

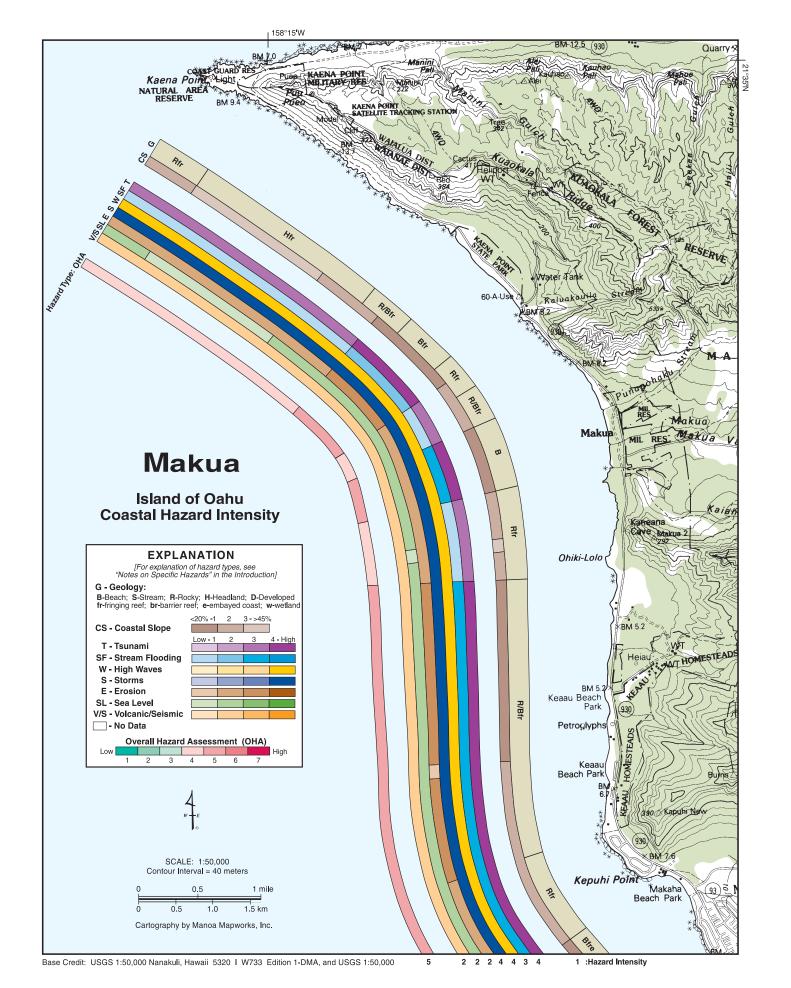




Waianae

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#### Makua

he Makua coast from Makaha Beach Park to the remote and rugged Kaena Point, is mostly rocky and narrow. Emerged Waimanalo-age carbonate reefrock borders the coastline near Makaha while, beneath the steep headlands of Kaena, basalt boulders dominate the coast. Features that appear to be alluvial fans or rock slides along the Kaena coast reveal that these cliffs are actively eroding. A few isolated pocket beaches exist between these rocky outcrops. At Makua, a platform of subtidal beachrock supports a perched sandy beach. The low-lying coastal road, which was overwashed by storm waves from Hurricane Iniki, gives way to a foot trail along the steep headland northwest of Kaena Point State Park. Scattered fringing reefs surround the rocky points and small sandy embayments. Large sand fields offshore of Makaha Beach Park merge with smaller elongated sand channels to the west. This region is dominated by high wave energy from North Pacific swell, especially in the winter and spring, however it is largely sheltered from active trade winds. The Makua coast is dominated by a fairly arid climate and stream flooding, while not a perennial threat, does occur from time to time.

The Overall Hazard Assessment (OHA) is moderate to high (5) along Keana Point State Park beach , Makua beach, and south of Ohiki-Lolo where the threat of tsunami is high and

stream flooding is moderately high, except along Kaena Point State Park where it is moderately low because of a lack of coastal streams. The OHA is moderate (4) along the steeper headlands between Kaena Point State Park and Makua and near Ohiki-Lolo where the tsunami hazard is moderately high and stream flooding is low. The threat of high waves, up to 20 and 25 ft on the outer reefs, comes annually during the winter and spring, and as a result, is ranked high. The Makua



Sandy beachs are separated by rocky headlands along the Makua Coast.

coast is vulnerable to both Kona storms and hurricanes tracking to the west of the Hawaiian Islands, and in the past has experienced considerable flooding, overwash, and wind damage from these events. As a result, a high hazard ranking has been given to storms along this coast. Erosion is ranked moderately low along the rocky cliffs in the western portion of Kaena State Park and south of the park to Ohiki-Lolo. Erosion is ranked moderately high for the lowerlying regions and beaches just inside Kaena Point State Park, and the entire shoreline south of Ohiki-Lolo, except for the steep-sided and rocky Keaau Beach Park, where it is ranked low. Sea-level rise is also a low to moderately low threat due to the rocky coastline. The volcanic/seismic hazard is ranked moderately low here as it is for the whole northern half of Oahu, from Makaha to Kaneohe Bay, which is removed from the Molokai Fracture Zone and other known regions of seismicity.

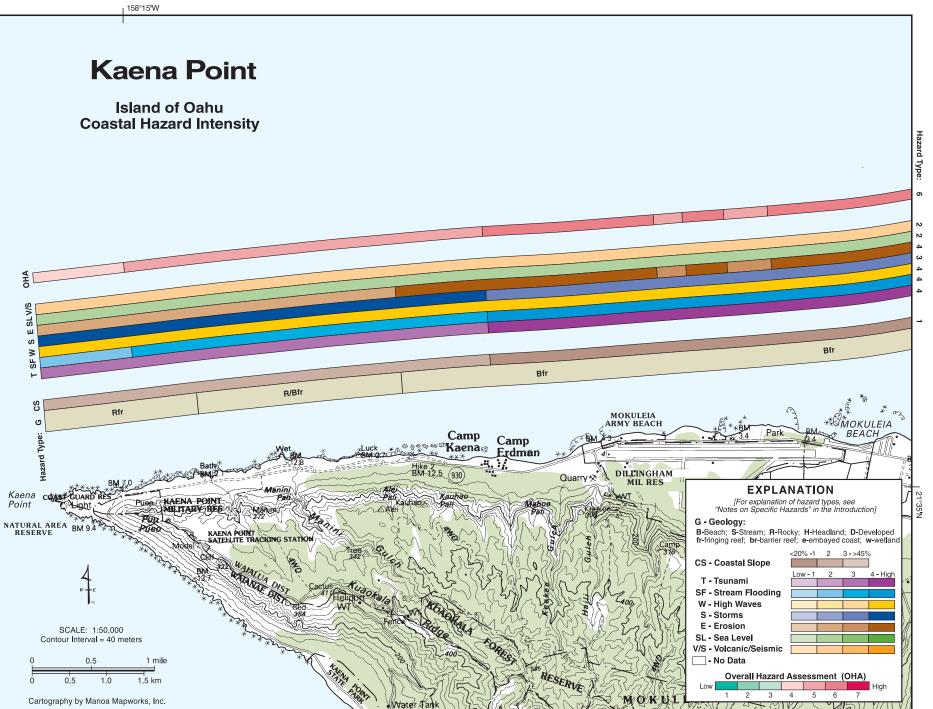
#### **Kaena Point**

long the north coast, from Kaena Point to Mokuleia, broad intertidal and subtidal wave-abrasion platforms are carved into Waimanalo-age limestone, reflecting the long history of great wave activity along this shoreline. A low-lying platform of fossil reefrock is elevated 3-6 ft above mean sea level and extends from Mokuleia to within 0.5 mi of Kaena Point. Isolated sandy beaches are found at breaks in the rocky bench and widen toward Mokuleia where they connect with small offshore sand fields. Modern intertidal erosion cuts into the elevated limestone testifying that wave energy and bioerosion are high at the shoreline. Offshore lies an extensive fringing reef complex. At Kaena Point, a partially vegetated Holocene dune field lies near sea level and is active in the trade winds and southerlies. Efforts to reduce erosion along the Mokuleia shoreline by implementing seawalls have essentially failed and instead have led to substantial beach loss.



The rugged, rocky coast between Kaena Point and Mokuleia experiences trade winds nearly 70% of the year.

The Overall Hazard Assessment (OHA) along the Kaena Point coast increases from moderate (4) at the point to high (6) along the low-lying sandy beaches of Camp Erdman and Mokuleia Beach, where the coastal slope is lowest and chronic erosion is diminishing Mokuleia's sandy beach. Between Kaena Point and Camp Erdman, where stream flooding is greatest, and along the hard limestone shoreline west of Mokuleia Beach, the OHA is moderate to high (5). Tsunami and stream flooding are ranked high along the lower slopes between Camp Erdman and Mokuleia, while

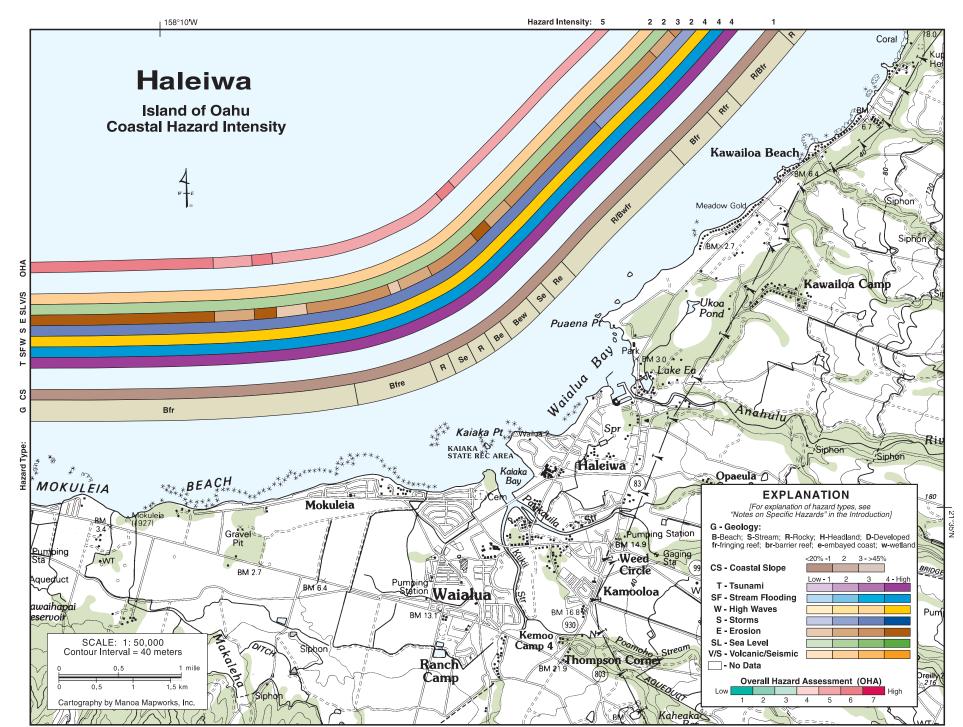


Base Credit: USGS 1:50,000 Kaena Point, Hawaii 5321 II W733 Edition 1-DMA

towards Kaena Point they are only moderately high because of the higher coastal slope. Tsunami flood heights of 36, 30, and 22 ft were observed at Kaena Point in 1946, 1952, and 1957, respectively. Stream flooding at Kaena Point is reduced further to moderately low, as this region is far removed from the drainage of the Kuaokala uplands. The hazard due to high waves is high throughout this region on the North Shore, where winter swells commonly reach heights between 20 and 25 ft. Kaena Point, at the northwestern tip of Oahu, is vulnerable to Kona storms and high trade

winds, as well as hurricanes. As a result the storm hazard is ranked high along the western half of the region, where hurricane force winds from hurricanes passing along the west shore of Oahu may be encountered. It is ranked moderately high toward the east, where the coast becomes sheltered from hurricane and Kona storm energy. Erosion is high along the isolated sandy beaches of Camp Erdman and Mokuleia, but moderately low along the hard limestone shoreline and rocky Kaena Point. The sealevel rise and volcanic/seismic hazards are ranked moderately low.





Base Credit: USGS 1:50,000 Kaena Point, Hawaii 5321 II W733 Edition 1-DMA



Narrow beaches and wide fringing reefs line the Mokuleia and Haleiwa coastal areas.



#### Haleiwa

with the confluence of the Kiikii and Paukauila streams and the Anahulu River. A long and narrow beach, bordered in many places by deteriorated seawalls and revetments, extends from Mokuleia to Kaiaka Bay. Rocky outcrops of limestone compose both Kaiaka and Puaena points. To the northeast, the coast toward Kawailoa Beach consists mostly of interspersed sand beaches and 3-6-ft rocky escarpments of basalt or limestone. Broad wave abrasion platforms extend offshore of Mokuleia Beach, but narrow toward Kawailoa Beach. This is a high wave-energy coastline that receives some of the largest breaking waves in the state. In 1969, for example, wave heights of between 30 and 35 ft were recorded offshore of Haleiwa, and in 1998 as high as 50 ft. It is also a low-sloping coast, and near the stream mouths wetlands and ponds are found. The only boat harbors along the entire North Shore of Oahu are found inside Kaiaka and Waialua Bays.

The moderate to high (5) to high (6) Overall Hazard Assessment (OHA) for the Haleiwa coast is largely influenced by the low coastal slope and a history of high wave energy and stream flooding. Additionally, where erosion is ranked high along Mokuleia, and Alii Beach Park in Haleiwa, the OHA is ranked high (6). The tsunamis of 1946, 1952, and 1957 generated flood heights of 11, 17, and 17 ft, respectively, along the Haleiwa coastline. In 1932, between 26 and 30 in of rain fell in a 24 hr period, resulting in extensive local flooding. Because of this history and the low coastal slopes found here, hazards due to tsunami, stream flooding, and high waves are ranked high along this coast. The storm hazard along this coast is moderately high, except northeast of Kawailoa Beach where the threat from hurricanes is reduced because of higher slopes and local sheltering. Erosion is high along the western segment of the Mokuleia shoreline and at the Anahulu River mouth, and moderately high along the eastern portion of Mokuleia and between Puaena Point and Kawailoa Beach. It is reduced to moderately low and low at three sites in Mokuleia, where the wide offshore reefs and scattered rocky carbonate outcrops onshore help buffer the coastline from wave energy. Sea-level rise is ranked moderately low throughout this region compared to Maui and the Big Island. The hazard due to volcanism and seismicity is also ranked moderately low as it is throughout the northern half of Oahu.

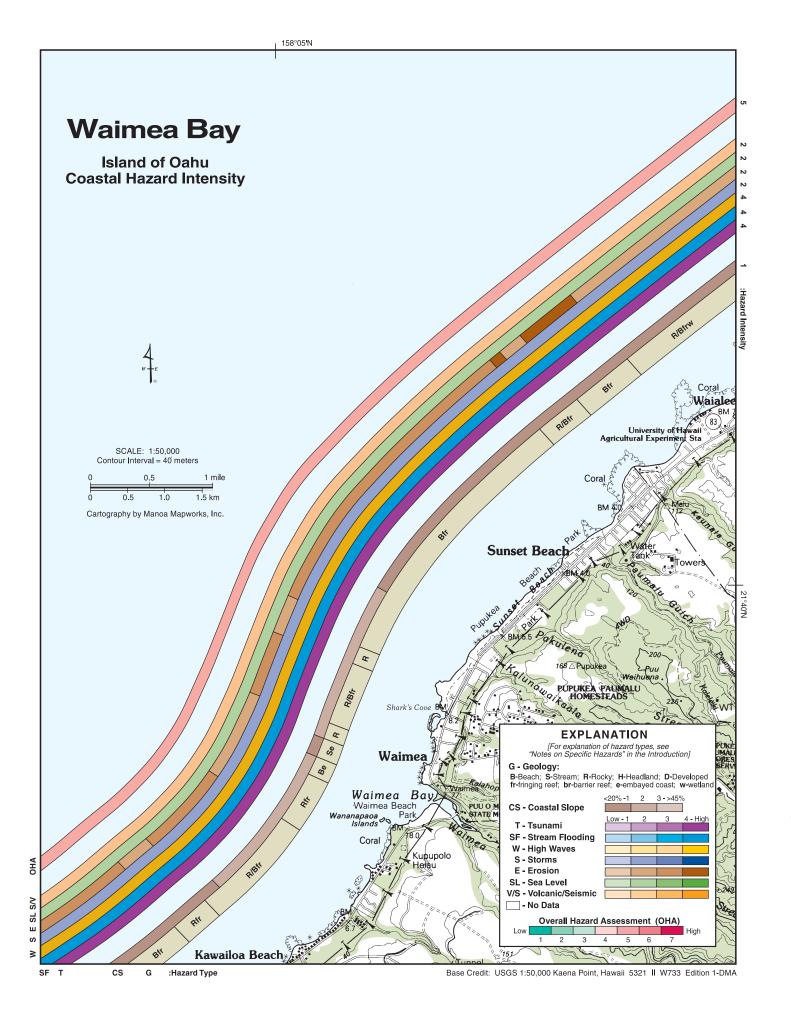
## **Waimea Bay**

ome of the world's best surf breaks are found along the Waimea Bay coastline, where winter waves annually reach breaking heights of 20 to 25 ft. Small pocket beaches along the Kawailoa Shoreline give way to a rocky basalt coast south of the beautiful wide beach and stream mouth at Waimea Bay. Long, coarse-grained sand beaches extend between Sunset Beach and Waialee. Isolated outcrops of basalt and reefrock harden the shoreline near Pupukea, Sunset Point, and Waialee Point. The coastal slope is steeper near Waimea Bay, but gradually decreases toward Sunset Beach where it coincides with a low coastal terrace that reaches northeast to Kahuku (see Kahuku map). Fringing reefs (mostly fossil) cover most of the offshore region of this coast.

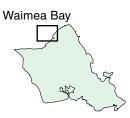
The Overall Hazard Assessment (OHA) for the Waimea coast is moderate to high (5), which is primarily a result of the susceptibility to high wave energy and stream flooding. In 1946, 1952, and 1957, tsunami runup of 19, 20, and 22 ft, respectively, inundated Waimea Bay. Stream flooding, especially in the flash flood prone Waimea River Valley, historically has been significant, and high wave events annually overwash the coastal road and cause damage to coastal property. For these reasons, the hazard due to tsunami, stream flooding, and high waves are ranked high. While storms like Hurricane Iwa have been known to produce 50-55 mph winds along this coast, the hazard due to storms is ranked moderately low relative to other areas in Hawaii. Erosion is ranked moderately low in Waimea Bay and along hardened coastlines, and moderately high for most of the long sandy beaches to either side of Waimea and along Pupukea Beach to Sunset Beach. It is also ranked high at the sandy beaches along the coastal terrace near Waialee. The hazard due to sea-level rise is ranked moderately low here as it is for most of Oahu, which is experiencing only moderate rates of rise. The volcanic/seismic hazard is also ranked moderately low here in the northern half of Oahu.

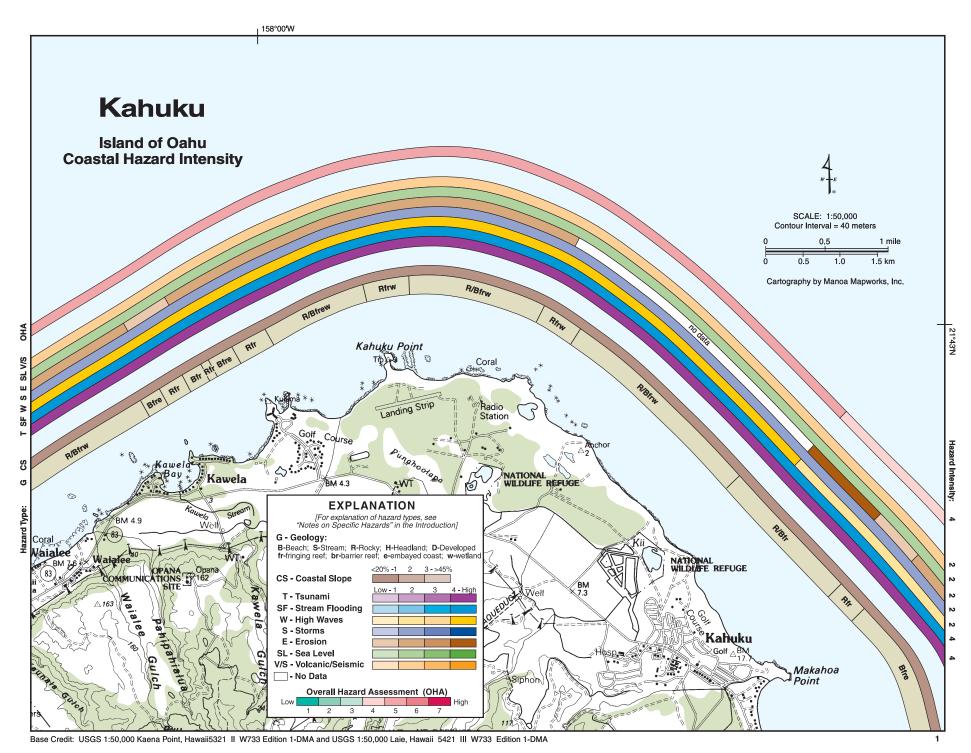
The Waimea coast looking southwest toward Kawailoa.











Kahuku

Sand dunes and perched beaches along Kahuku Point are continuously reshaped by the persistent trade winds.



#### Kahuku

he northernmost tip of Oahu reaches around Kahuku Point where low coastal terraces host one of the most extensive wetlands in the state. Relict and modern dune fields lie seaward of mixed-use aquaculture ponds and a wildlife sanctuary that provides habitat for birdlife. Rocky limestone cliffs encircle the embayments at Kawela and Kuilima bays. Lithified outcrops of eolianite along Kahuku and Makahoa points are scoured by solution weathering, intertidal bioerosion, and the relentless trade winds, creating a sharp and jagged surface that makes access to the shoreline difficult. Extensive ridges of beachrock on the foreshore are found along the entire area and are evidence of recent coastal erosion and retreat. Spectacular wind-swept sand formations mark much of the windward coast and have left limestone outcrops and islets offshore. Sand beaches are perched on benches of eolianite and old reefrock or beachrock between Kahuku Point and Makahoa Point. Here some active dunes also exist seaward of vegetated Holocene dunes. The fringing reefs widen east of Kahuku Point due to the decreased wave energy away from the winter swell of the north shore.

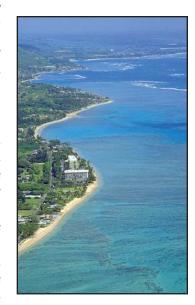
The Overall Hazard Assessment (OHA) is moderate to high (5) from Waialee around Kahuku Point to just north of Kahuku town, while south to Makahoa Point, where the wave energy is lower, it is reduced to moderate (4). The tsunami and stream flooding hazards are ranked high along the entire Kahuku coastline. During the 1946 and 1957 tsunamis, flood inundation heights of 27 and 23 ft were recorded at Kahuku Point. The hazard associated with high waves is ranked high around the entire Kahuku Point, but is reduced to moderately low southeast of the Point where the coast is partly sheltered from north swell. The storm threat is ranked moderately low along the Kahuku coast because it is partly sheltered from the impact of the majority of tropical storms that historically track to the west and south of Oahu. Erosion is ranked moderately low for the small embayments lining the western portion of Kahuku Point, except along the rocky point immediately northeast of Kawela Bay beach where it is low. Along the northeast side east of Kahuku Point there are no available data, except at the town of Kahuku, where erosion is ranked high, but is then reduced to low along Makahoa Point. The hazard due to sea-level rise here is moderately low. The volcanic/seismic hazard here in the northern half of Oahu is also ranked moderately low.

#### Laie

South of Kahuku, along the windward coast to Hauula, the narrow coastal plain is marked by deeply-carved bays separated by prominent rocky points that reach seaward. The embayments of Malaekahana and Laie Bay consist of relatively pristine sandy beaches, while those farther south at Laie and Hauula have been severely altered by development and suffer from chronic erosion. This is a strong trade wind environment, and eolian features, both modern and relict, are pervasive throughout the region. Small emerged carbonate islets formed of lithified sandstone (eolianite) lie offshore of Kalanai and Laie Points. The shoreline is characterized by an extensive fringing reef complex associated with a broad, shallow, and generally smooth reef flat. Near Hauula the beach is highly developed with seawalls and revet-

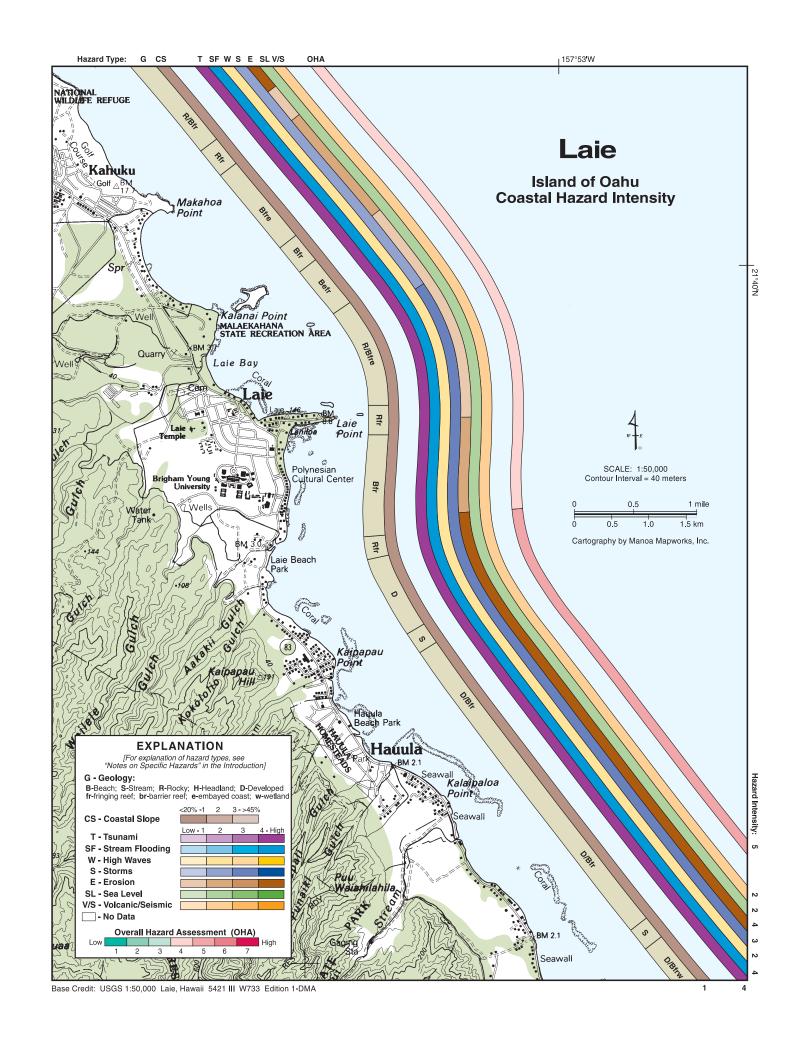
ments, many of which are aged and appear to be failing in their attempt to protect seaside properties. Vertical relief along this coastline is relatively low, but does increase slightly towards the south and near the rocky outcrops of Makahoa and Laie Points. Several streams that empty the Koolau Range transport upland sediments to the coastal zone during intense rainfall events. This is reflected in the beach sediment composition.

Chronic erosion and beach loss south of Laie Beach Park is responsible for the difference in the Overall Hazard Assessment (OHA) of moderate (4) for the northern half of this region and moderate to high (5) for the southern portion. Tsunami flood heights of 27 and 23 ft associated with the 1946 and 1957 tsunamis were recorded just south of Kahuku. Flash floods and overflowing streams in this region are common. For example, in 1929, 11 in of rain falling in 11 hr brought floods to the lowlands, and on March 31, 1965, 4.5 in of rain was recorded in 1.5 hr at Punaluu! For these reasons, a high ranking is given to both the tsunami and stream flooding hazards. High waves become a significantly lesser threat south of Kahuku, as the coast becomes increasingly sheltered from winter swell. As a result, it is ranked moderately low.



Narrow beaches are being rapidly lost to sediment difficiencies, sea-level rise, and waves and currents along the low coastal plain between Hauula and Laie.

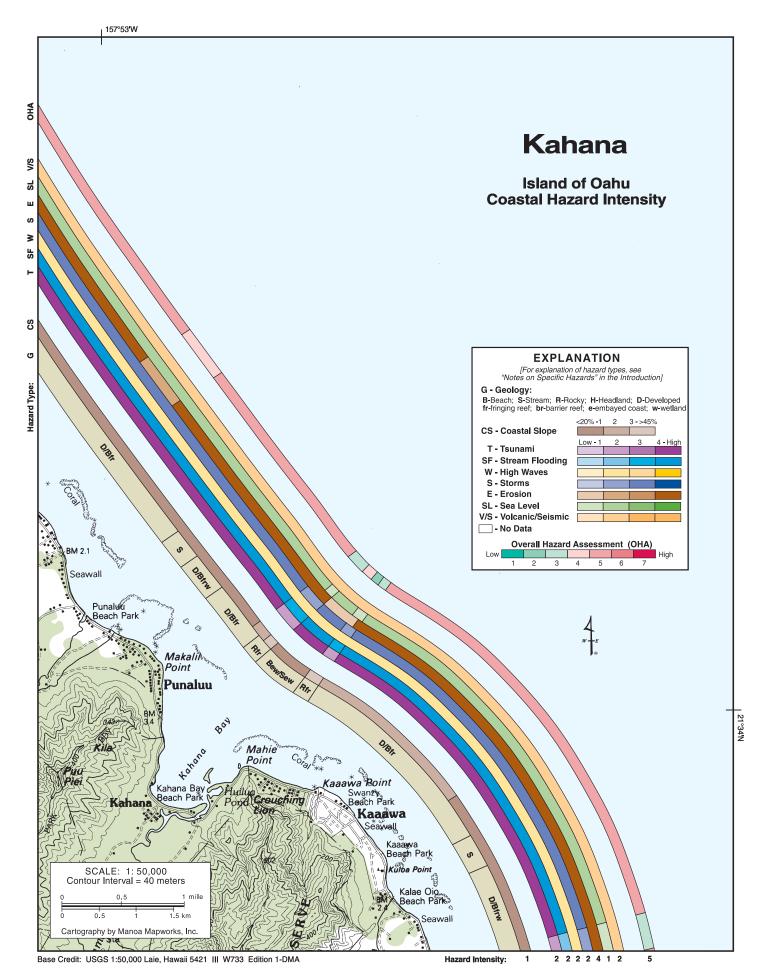
The hazard due to storms, however, is ranked moderately high south of Kalanai Point and moderately low to the north where the coast is more sheltered because storms usually approach from the east-southeast and have brought high winds and waves to this coast in the past. Erosion is significantly greater in the south near Hauula and Punaluu where shore-hardening structures, installed to stop coastal erosion, have exacerbated beach loss. Reflected waves off seawalls, revetments, and groins along Hauula and Punaluu often splash up onto the seaside properties and the coastal road at high tide, removing what little sand remains. Erosion of the embayed beaches in the north is ranked moderately low to low because it is partly mitigated by long rocky points that provide protection from extreme wave energy. Sealevel rise and volcanic/seismic threats are ranked moderately low along the entire region, as they are in most portions of northern Oahu where they are relatively low compared to other areas in Hawaii.











#### Kahana

The Kahana coastline is dominated by low-lying, narrow beaches with broad shallow fringing reefs extending offshore. This region is extensively developed and its narrow beaches suffer from chronic erosion and are nearly devoid of sand. Seawalls, revetments, and groins have been constructed along Punaluu and Kaaawa to protect coastal property at the expense of the sandy beach that provides a natural buffer for active shorelines. A broad reef flat extends seaward to a well developed fringing reef complex. Streams transport surface runoff and upland sediments to the coastal areas at Punaluu and Kalae Oio Beach Parks. Steeper rocky ramparts and basalt boulder piles surround Kahana Bay. The beach at the mouth of Kahana Stream is the widest in the region and consists of very fine mixed volcanic and carbonate sand that grades into carbonate-dominated sand offshore. A wetland exists at the stream mouth and fish ponds are still visible along the southern flanks of the bay. After heavy rainfall, Kahana Stream transports enough upland sediment to create a large plume of suspended silt that extends into the center of the bay.

The Overall Hazard Assessment (OHA) is moderate to high (5) north and south of Kahana Bay, where the lower coastal slopes are more susceptible to tsunami inundation. Inside Kahana Bay, the OHA is moderate (4) while on the north side it is low (3) and along the southern side out to Mahie Point it is very low (2), due to the reduced threat of waves and flooding along the steeper rocky cliffs that flank the bay sides. The tsunami and stream flood hazards are high along the Kaaawa coastal zone and at the mouth of the Kahana Stream, where the

coastal slopes are low. On both sides of the bay, these threats are reduced by the presence of steep rocky headlands. The stream flooding hazard is high due to stream floods and flash floods that frequently inundate the coastal plain. For example, in 1963, 19 in of rain in a 24 hr period brought torrential floods to the lowlands. The high wave threat is ranked moderately low throughout the region because it is relatively sheltered from winter swell. High winds and waves associated with hurricanes and tropical storms as well as intensive trade wind storms passing



Very little sand remains along the narrow beaches of Kaaawa.

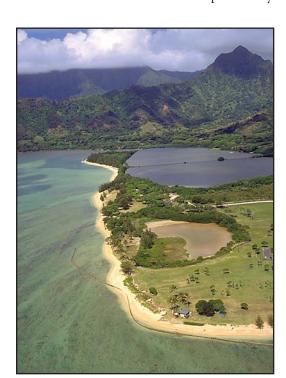
through the area, however, have caused considerable damage along this coast. In fact, the highest winds on Oahu during Hurricane Iwa (1982), which passed to the west of the island, were recorded along this portion of coast and are thought to have been accentuated as they descended over the steep windward cliffs of the Koolau Range. As a result, the storm hazard is moderately high, except at the steep headlands surrounding Kahana Bay, where it is moderately low. Erosion is ranked high along the entire coast except at the beach inside Kahana Bay, where it is downgraded to low. Sea-level rise and volcanic/seismic hazards are moderately low throughout the region as they are in most of the northern half of Oahu.

Kaneohe

#### Kaneohe

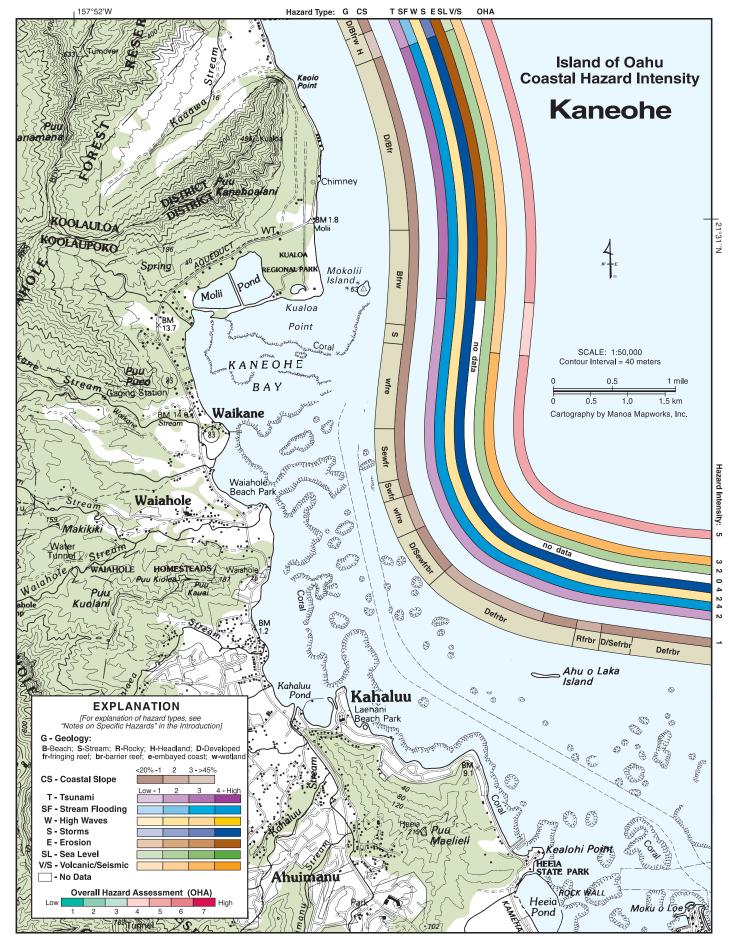
South of Kualoa Point, the coast is deeply embayed and bordered by isolated beaches of gravely mud, fish ponds, small mangrove forests, and shallow deltas of upland sediment deposited by the many rivers emptying the Koolau Range. This low-lying coastal plain is especially prone to, and has experienced, considerable damage from flash floods generated by intense runoff from the very steep slopes of the Koolau Range. In November of 1970, 11.5 in of rainfall were recorded in 4 hr in Kahaluu. Near Kahaluu, where Kaneohe Bay reaches its greatest depths, the fringing reef lies far offshore and is, in form and function, Hawaii's only barrier reef. A very shallow and broad subtidal shelf of fossil reef rock extends nearly a mile offshore, just seaward of the barrier reef. A prominent sand bar, Ahu o Laka Island, in the central portion of the coast parallels the shore and becomes exposed at low tides. Mokolii (Chinaman's Hat) Island, an erosional remnant of Koolau basalt, lies offshore near the seaward edge of the barrier reef. Wave energy at the shoreline is generally very low, but along the outer reef it is higher and dominated by trade wind swell, and under moderate storm conditions such as during the distant passage of Hurricane Fernanda in 1993, waves overwash the coastal road along the Kualoa Point.

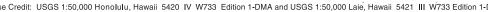
The Overall Hazard Assessment (OHA) for Kaneohe is moderate to high (5) except for the short stretch of coastline sheltered behind Kualoa Point that is ranked moderate (4). Tsunami activity in Kaneohe has historically been very low. It is ranked moderately high in the northern portion where Kaoio and Kualoa points are exposed to swell. South of Kualoa Point the tsunami threat is ranked moderately low where the coast is more sheltered. The low-lying Kaneohe Coast has had 20 major stream floods since 1936. As a result, the stream flooding hazard is ranked high throughout the area. The hazard due to high waves is ranked moderately low throughout the area, because it is largely reduced by the barrier reef complex and broad reef flat bordering the shoreline. The threat of storms along this low-lying, east-facing coastline is ranked high, because it faces tropical storms and trade wind storms that approach from the east. Erosion threatens the sparse sandy beaches that remain north of Kualoa Point

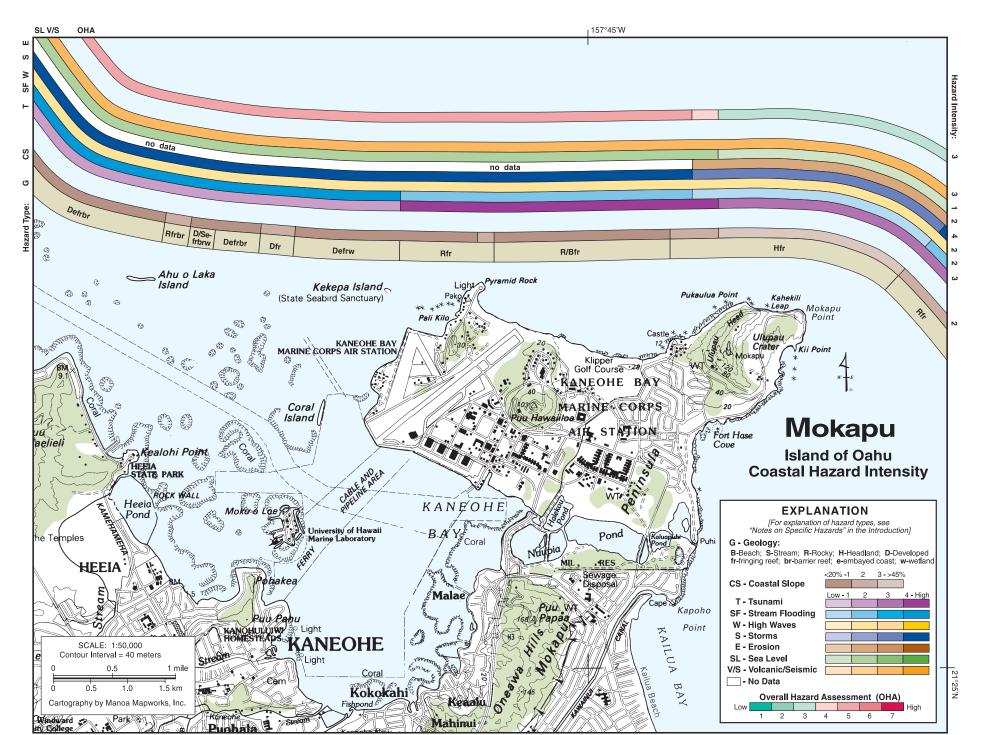


and hence has been ranked high there. Little data exists on erosion rates within Kaneohe Bay, where development has changed the shoreline, and so a ranking has not been given. Hazards associated with sea-level rise are relatively low along this entire coastal segment. The volcanic/seismic hazard is moderately high in the south, due to its proximity to the Molokai Seismic Zone, and moderately low in the north.

A sand spit extending west from Kualoa Point functions like a barrier island to the Molii Fish Ponds.







Base Credit: USGS 1:50,000 Honolulu, Hawaii 5420 IV W733 Edition 1-DMA and USGS 1:50,000 Koko Head, Hawaii 5420 I W733 Edition 1-DMA



A bird's-eye view of Mokapu Peninsula, home to the Kaneohe Bay Marine Air Corps Station.



## Mokapu

he Mokapu Peninsula, site of the Kaneohe Bay Marine Corps Air Station, separates Kaneohe Bay from Kailua Bay. It was formed by a group of secondary volcanic eruptions that produced Ulupau Crater, Puu Hawaiiloa, and Pyramid Rock sometime since the middle Pleistocene. The shoreline is steepest at the rocky headland where cliffs seaward of Pyramid Rock and Ulupau Crater are pounded by high waves. A long beach lies at the north end of the peninsula, and some active dunes exist above isolated basalt boulder outcrops. Several fish ponds occupy the low-lying isthmus of the peninsula, which may have been submerged by a higher relative sea level during the late Holocene, isolating the headland from the rest of Oahu making Mokapu an island. The shoreline is low and flat along the Kaneohe side and heavily developed with seawalls, fish ponds, seaplane ramps, and dredged channels. A basaltic outcrop, Moku o Loe (Coconut Island) and an emerged limestone platform, Kekepa Island, lie within Kaneohe bay along the northwest side of Mokapu Peninsula. The Kailua side of the peninsula consists primarily of a small rocky limestone escarpment between Kapoho and Kii Points with some beachrock and perched beaches. The north end of Kailua Beach begins at the mouth of the Kawainui Canal, which drains the Kawainui Marsh. An extensive fringing reef borders the entire coastline.

The Overall Hazard Assessment (OHA) north of Pukaulua Point on Mokapu Peninsula is moderate to high (5) reflecting the low coastal slope and proximity to the drainages of the Koolau Range. The OHA is reduced to moderate (4) for the short stretch near Pukaulua Point where the coastal slope steepens, and is further reduced to moderate to low (3) at the rocky Mokapu Point where the coast is steepest and farthest removed from potential stream flooding originating in the Koolau range. A 21 ft runup, recorded at Mokapu Point, was generated by the tsunami of 1946. However, because the barrier reef complex and broad reef flat of Kaneohe Bay help to dissipate high wave energy, the tsunami hazard is ranked moderately low north of Pyramid Rock. At the low-lying beach on the north edge of the peninsula, tsunami flooding is ranked high, and at the rocky headland at Mokapu Point where the slope is steeper, it is ranked moderately high. Stream flooding is ranked high along the low coastal plain of Kaneohe, but is reduced to the south, where the Mokapu headland becomes removed from the drainage of the Koolau Range, and along the steep slopes at Mokapu Point. The wave hazard is ranked moderately low along the entire portion of Mokapu because it is relatively sheltered from winter swell. Combined with high winds, the storm hazard is ranked high throughout the region except at the steep, rocky Mokapu Point, where it is moderately high. Erosion data is unavailable for the Kaneohe coast. However, along Mokapu Point, erosion is ranked moderately low because of the hard rocky headland. The threat of sea-level rise is moderately low along the Kaneohe coast and low at the steep rocky point. The volcanic/seismic hazard here resembles that of southern Oahu, which is ranked moderately high in accordance with its proximity to the Molokai Seismic Zone.

#### Kailua

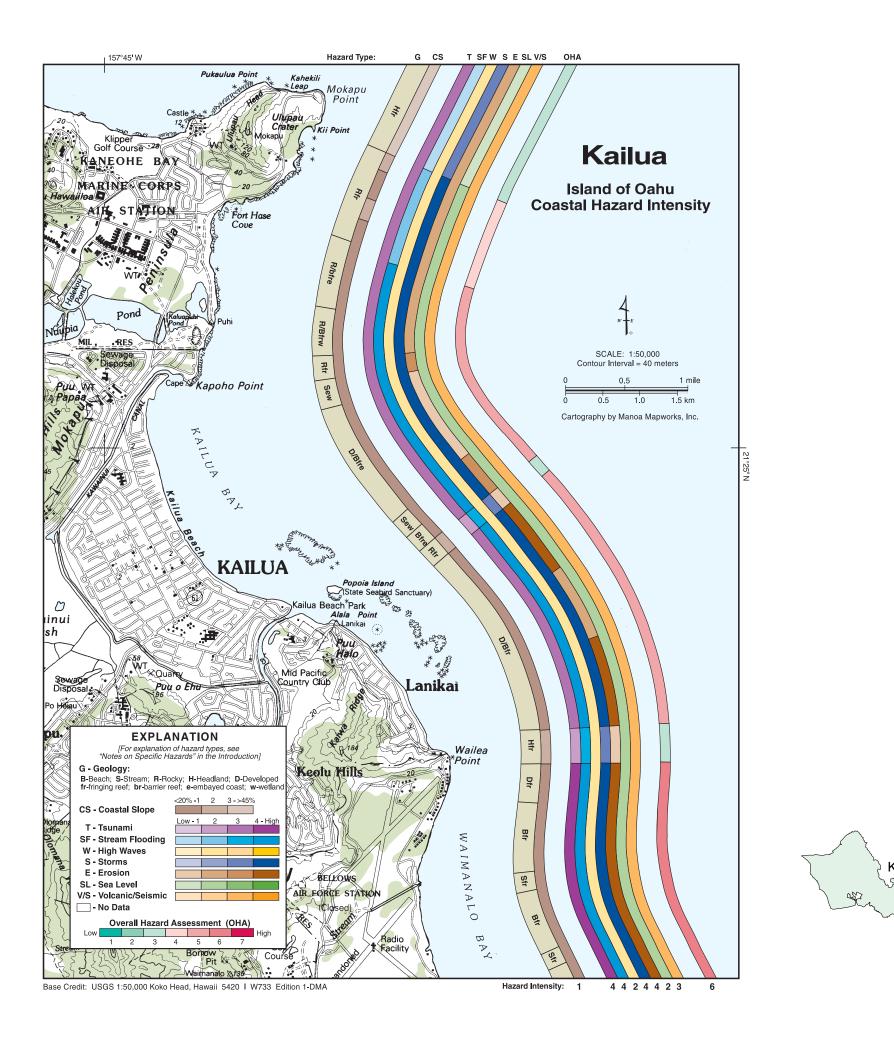
South of Mokapu Point to Kapoho Point, the rocky volcanic headland gives way to emerged reefrock and eolianite, and then to the long, sandy beaches of Kailua, Lanikai, and Waimanalo. Canals that drain the interior valley, separate these beaches from isolated outcrops of basalt and emerged limestone. The densely developed coastal plains of Kailua, Lanikai, and Waimanalo are gently sloping and believed to have been submerged by a higher relative sea level between 1,500 and 4,000 years ago. Relict and modern dune ridges and fossil beaches compose most of the coastal plain at Kailua and Waimanalo. Popoia Island, an emerged limestone islet, lies along an extensive fringing reef complex offshore. The wave energy here is moderate. A substantial proliferation of seawalls and revetments south of Alala Point has accelerated beach loss in Lanikai, no doubt by impounding sand. Revetments, emplaced in front of the airfield at Waimanalo, also appear to have exacerbated beach loss on the north side of Waimanalo Beach and possibly led to impacts in south Lanikai.

The Overall Hazard Assessment (OHA) along the Kailua coast reflects the variable nature of alternating steep, rocky outcrops, stream mouths, and low-lying sandy beaches. The OHA increases from moderate to low (3) along Mokapu Point to moderate (4) between Kii Point and Fort Hase Cove where stream flooding is moderately low. Along the low-lying sandy beaches of Kailua and Lanikai, where stream flooding and erosion are ranked high in places, the OHA is moderate to high (5), except at Alala and Wailea Points where it is moderate to low (3) due to the lower tsunami, stream flooding, storm and erosion hazards at those steep, rocky headlands. South of Wailea Point, the OHA is ranked high (6) due to the high tsunami hazard along Waimanalo. Tsunami inundation along the Kailua waterfront historically has not been as high as in Waimanalo, and as a result, the tsunami hazard is ranked moderately high along Kailua and Lanikai exept at the Alala and Wailea Points and high in Waimanalo. Stream flooding is ranked low at the north end of Mokapu Point, moderately low near the south side of Mokapu Point, and high along the low-lying developed coastline of Kailua, Lanikai, and Waimanalo, where prolonged and flash flooding are frequent, year-round occurrences. During the winter of 1987, for example, a slow-moving storm brought about 2-5 ft of flooding to Kawainui Marsh (just west of the town of Kailua) and surrounding area, while in 1970, over 11 in of rain fell on Waimanalo in only 4 hr. The Kailua coast, facing east and protected by the extensive fringing/barrier reef offshore, is relatively sheltered from winter north swell, so the high wave hazard is ranked moderately low. Erosion is low and moderately low along the rocky outcrops. It is also moderately low in the central portion of Lanikai, where the beach

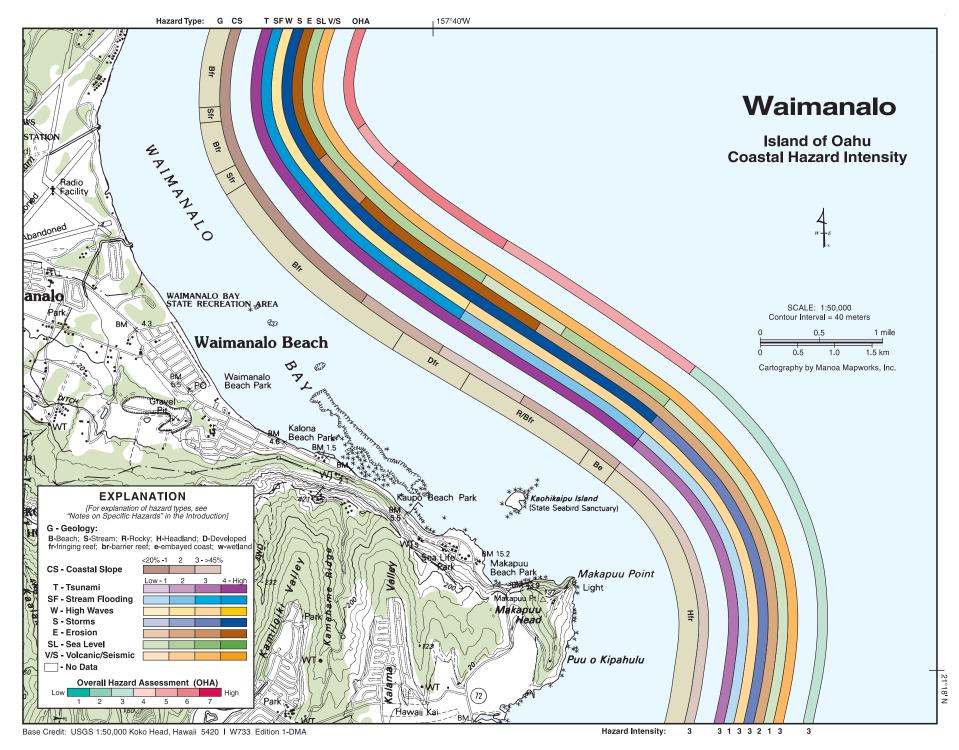
is presently accreting at the expense of beach loss along its margins. At stream mouths and especially along the northern and southern ends of Lanikai, where there is chronic beach loss, the erosion hazard is ranked high. Sea-level rise is ranked moderately low here as it is along most of Oahu's shores, where rates of rise are moderate. The volcanic/seismic threat is ranked moderately high in Kailua, due to its proximity to the Molokai Seismic Zone.



Chronic beach loss along north Lanikai since the 1980's has left the shoreline lined with seawalls. In the distance, a wide beach at the Kailua Beach Park is a favorite island playground.



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Fine, white sands border the nearly perfect cresent of Waimanalo Bay.



#### Waimanalo

he long Waimanalo Beach, backed by vegetated dune ridges, lies on a developed coastal plain that narrows south toward Kalona Beach Park. There it abruptly changes to a rocky limestone coast with isolated basalt boulder deposits and small pocket beaches south to Kaupo Beach Park. A large basalt flow extends towards Kaohikaipu Island (Rabbit Island), just north of the last sandy beach found on the windward coast at Makapuu Beach Park. The relatively low topography at Waimanalo abruptly steepens at Makapuu where the southern end of the Koolau Range abuts the shore and culminates at Makapuu Head. The wide fringing reef of Waimanalo works to effectively dissipate trade wind wave energy. The fringing reef is absent at Makapuu Beach enabling larger waves to reach the shore there. Stream flooding poses one of the greatest threats along the Waimanalo coastline, where intense rainfall over the steep Koolau Range may generate high rates of surface runoff that collects on the low coastal plain. In November of 1970, for example, 11.5 in of rain fell in only 4 hr, and in March of 1958 13.8 in of rainfall were recorded in 24 hr, flooding Waimanalo with 3 ft of standing water. To the north, beach loss occurs at the 800 ft-long Bellows revetment, and along the southern shore where coastal properties are protected by seawalls, beaches suffer sand deficiency and chronic erosion.

The Overall Hazard Assessment (OHA) varies between high (6) along Waimanalo Beach, where erosion and stream flooding are highest, to moderate to high (5) south of Kalona Beach Park, where erosion and stream flooding are moderately low. The OHA is further reduced to moderate to low (3) south of Makapuu Point, where few streams exist and runoff is low. The tsunami hazard for the Waimanalo coast is high along the low-lying embayment south to the headland at Makapuu Point. The storm hazard is also ranked high along this portion of the coast, where hurricanes, such as Hurricane Kate in 1976, have brought waves as high as 15 ft to these shores. Winds up to 82 mph, associated with Hurricane Iwa in 1982, were also recorded in the Waimanalo area. Trade wind gales are also common, though not annual events. Stream flood hazard is high north of Kaupo Beach Park, where flash flooding such as in March of 1958, can inundate the town of Waimanalo with several feet of water. It is moderately low between Kaupo Beach Park and Makapuu Point and low south of the point. The threat of high waves is moderately low in the northern portion, which is partially sheltered from winter swell and protected by the extensive fringing reef offshore. To the south of Kaupo Beach it is ranked high, due to its greater exposure to trade wind swell and both winter and southern wave energy that refracts towards Makapuu Beach. Erosion is high to moderately high throughout the beach system of Waimanalo, where retreat of the coast is intense, but moderately low south of Kaupo Beach Park where it is mitigated by the rocky basalt coastline. Sea-level rise, while ranked only a moderately low hazard for Waimanalo and Makapuu Beaches, is ranked even lower for the rocky, resistant headlands at Kaupo Beach Park and Makapuu Point. The volcanic/seismic hazard is ranked moderately high being so close to the Molokai Sesimic Zone.

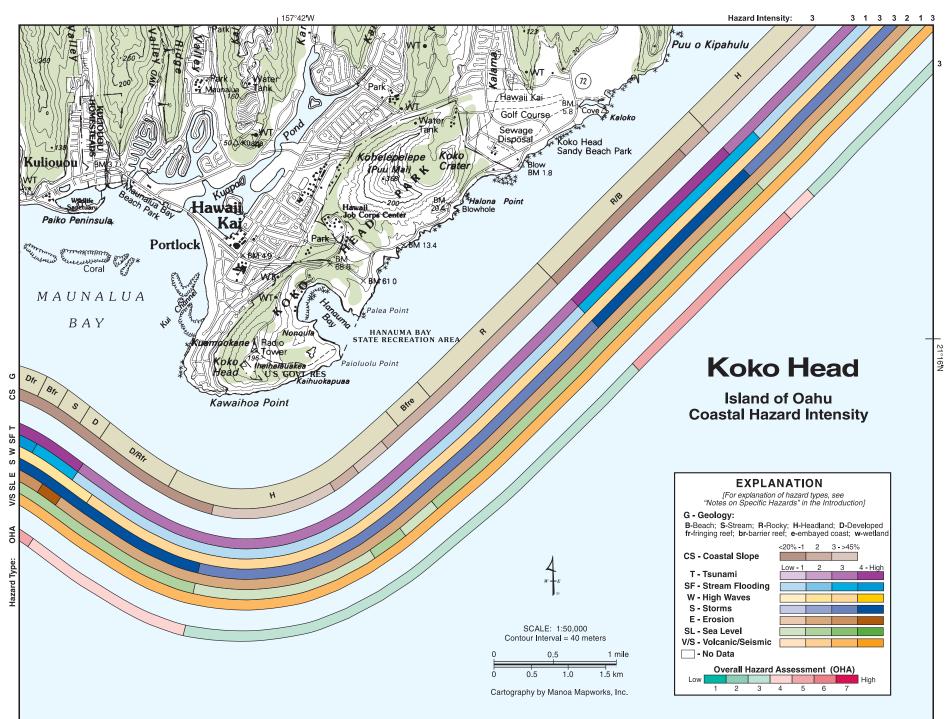
#### **Koko Head**

he steep and rocky headland of Makapuu Point (see Waimanalo map) flattens out westward to a coastal terrace but remains rocky and partly covered by perched beaches and dune fields before reaching Sandy Beach Park. West of Sandy Beach to Hawaii Kai, the coastline is steep and rocky, with cliffs and small embayments. Sandy Beach is the most prominent beach system in this region and maintains a small sand field offshore. Sandy Beach is famous for its intense shorebreak. The shoreline northeast of Sandy Beach consists primarily of basaltic boulders and volcanic outcrops but to the west is bordered by a low-lying bench that contours the coast through Hanauma Bay. Above lie steep cliffs of Pleistocene volcanic tuff deposits. Several blow holes near Holona Point provide exciting views of water plumes that are sent billowing high into the air as waves force water through naturally formed cracks in the basalt and tuff. A broad reef flat inside Hanauma Bay offers divers access to the most beautiful and perhaps most sensitive wildlife spectacle on Oahu. Around Koko Head, the Portlock coast is heavily developed along steep cliffs and is devoid of sandy beaches below. Seawalls and minor groins exist along a sand spit at the mouth of Kuapa Pond and the Hawaii Kai coastline. The patchy fringing reef that exists along the Sandy Beach coast, fades away seaward of Hanauma Bay and Koko Head, but is well-established in Maunalua Bay.



The Koko Head coast is largely rocky, except for the central portion surrounding Sandy Beach.

The Overall Hazard Assessment (OHA) for the majority of this coastline is ranked moderate to low (3), due to the steep and resistant nature of the cliffs and headlands that flank the south shore. However, at the lowlying area of Sandy Beach the OHA is elevated to moderate to high (5), where the tsunami, stream flooding, and storm hazards are higher. Between Kaloko and Puu o Kipahula, and just west of Kawaihoa Point, the OHA is moderate (4). The tsunami and stream flooding hazards are high and moderately high, respectively, for the short stretch of low-lying coast



Base Credit: USGS 1:50,000 Koko Head, Hawaii 5420 I W733 Edition 1-DMA

between Kaloko and Halona Points. Elsewhere, the coastal slope is sufficiently high that the tsunami hazard is moderately low and the stream flooding hazard is low. This coastline borders the 35 mi wide Molokai Channel that is known for its rough sea conditions throughout the year. Winds and waves traveling through the channel are often intensified as they accelerate between Oahu and Molokai. While wave heights do not often surpass 10 to 12 ft, they can build very rapidly as they make landfall from the very deep water of the channel. This makes for intense wave energy as waves stack up at the shore and collide with the steep Sandy Beach and rocky cliffs to the west. The threat from waves is high throughout this

coast as it receives substantial swell in winter and summer. The storm hazard is greatest for the low coastal areas near Sandy Beach and west of Koko Head, where it is ranked high. For the rocky cliff coastline between, it is moderately high. Erosion is moderately low throughout the entire region, as the rocky shoreline mitigates this threat. The sea-level rise hazard is moderately low throughout the region, except at the steeper headlands at Koko Head where it is reduced to low. The volcanic/seismic hazard here is ranked moderately high in accordance with its proximity to the Molokai Seismic Zone.



Base Credit: USGS 1:50,000 Honolulu, Hawaii 5420 IV W733 Edition 1-DMA and USGS 1:50,000 Koko Head, Hawaii 5420 I W733 Edition 1-DMA



**70** 

Very narrow beaches are slowly being lost to chronic erosion and shoreline hardening along Maunalua Bay between Diamond Head and Hawaii Kai to the southeast.



0.5

1.0

Cartography by Manoa Mapworks, Inc.

1.5 km

157°45'W

### **Diamond Head**

he Diamond Head coastal zone stretches from Waikiki to Hawaii Kai, in the eastern portion of Maunalua Bay. One of Hawaii's shallowest and widest reef flats exists along Maunalua Bay. Residential and commercial development is widespread along the low-sloping terrace comprised of emerged fossil coral reef. Diamond Head Crater and Kupikipikio Point (Black Point), formed by recent volcanic eruptions, are steep headlands that separate the beaches of Waikiki from the narrow sand and gravel beaches of Kahala. Intensive development and construction of seawalls, revetments, and groins along the Kahala and Niu coasts have been accompanied by chronic beach loss. In many locations, the waterline at low tide coincides with the base of a seawall. Streams and drainage canals carry surface runoff and upland sediment from the Koolau Range and urbanized valleys to the sea, in some places creating deltas of silt and volcanic sand.

The Overall Hazard Assessment (OHA) for the Diamond Head coastline is moderate to high (5) except along the low sloping coastal areas of Niu Valley and between Wailupe and Kahala which are most susceptible to flooding and wave damage, and are ranked high (6). At the steep headland of Diamond Head Crater, the OHA is moderate to low (4). The tsunami and storm hazards along the Diamond Head coast reflect the influence of topography. They are both ranked high except at Diamond Head, where they are reduced to moderately high. The stream flooding hazard is ranked high east of Kahala, where stream discharge in Niu Valley and Aina Haina have reached rates of 3600 ft<sup>3</sup>/sec. The saddle-like topography west of Waialae Beach Park, directs runoff either toward Honolulu through the Ala Wai canal or east toward the canal at Waialae Beach Park. This area is also far removed from the Koolau Range and the coastal slope is great, so stream flooding is ranked moderately low. The threat of high waves that annually reach this coast in spring and summer is ranked moderately high. Erosion is high along the entire coast except at the steep Wailupe and Kupikipikio Point headlands. The hazard of sea-level rise is moderately low here where it is experiencing low rates of rise compared to other areas in Hawaii. The volcanic/seismic hazard is ranked moderately high as it is along all of Oahu's southern shores, due to their proximity to the Molokai Seismic Zone.